

# **PHYSICAL BASIS OF GEOGRAPHY**

A Textbook for Class XI

## **EDITORIAL BOARD**

Prof. Moonis Raza (*Chairman*)  
Prof. C. D. Deshpande  
Prof. Satyesh Chakraborty  
Prof. N. Anantapadmanabhan  
Prof. B. S. Patalkh (*Convenor*)

# **PHYSICAL BASIS OF GEOGRAPHY**

## **(A Textbook for Class XI)**

**A. B. Mukerji**



**राष्ट्रीय शैक्षिक अनुसंधान और प्रशिक्षण परिषद्**  
**NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING**

The first edition of this book was published in July 1977 by M/s. Pitambar Book Depot by permission of the National Council of Educational Research and Training. Subsequent editions have been published by the National Council of Educational Research and Training.

*First Edition*

July 1977  
Sravana 1899

*Reprinted*

March 1980  
Phalgun 1901  
May 1981  
Vaisakha 1903  
April 1982  
Chaitra 1904

P. D. ST. BB

© National Council of Educational Research and Training, 1977

DLDI, NCERT  
  
5514 F24288  
MUK

Rs. . 9.60

Published at the Publication Department by V. K. Pandit, Secretary, National Council of Educational Research and Training, Sri Aurobindo Marg, New Delhi 110016 and printed at Ashoka Offset Works, 308/2, Shahzada Bagh, Old Rohtak Road, Delhi 110035

## FOREWORD

This book follows the approach taken by the Council in developing a curriculum for Classes XI and XII.

An Editorial Board for Geography for the secondary and higher secondary stage was constituted under the Chairmanship of Professor Moonis Raza. The Editorial Board devoted considerable time to developing the syllabi in geography for Classes IX, X, XI and XII and then to the preparation of manuscripts of different books for the same.

The present book *Physical Basis of Geography* for Semester I of Class XI is one in the series. At this stage it has been our endeavour to develop a curriculum which would be more functional and problem-oriented. Further, it should serve as a basis for those students also who would go to colleges and universities or professional institutions for higher learning.

Our thanks are due to Professor Moonis Raza and his colleagues on the Editorial Board for preparing the syllabi and manuscripts of the books. We are grateful to Dr. A. B. Mukerji of Panjab University, Chandigarh, for the considerable pains he took in the preparation of this manuscript which was discussed and approved by the Editorial Board. Special mention may be made in this connection of Professor C. D. Deshpande who looked after this work personally and also contributed the first two chapters of this book explaining the nature and scope of geography as a discipline. The maps included in this book were prepared by Shri Purushottam. Our thanks are also due to Shri V. S. Chaudhary who rendered the script into Hindi in a very short time.

The preparation of curriculum and textbooks calls for considerable expertise and effort in planning the work, in screening, reviewing and editing the book and, finally, seeing it through the press. For all this I am grateful to my colleagues in the Department of Education in Social Sciences and Humanities, and particularly to Professor B. S. Parakh and to Smt. Savita Sinha who was assisted by Smt. Savita Verma. In fact, but for the dedicated and sustained work of Smt. Savita Sinha the book in its present form would not have seen the light of the day.

( vi )

Curriculum construction and development of instructional materials are on-going processes and hence every suggestion from the teachers in the light of their experience would be most welcome. These would be taken into account while bringing out the revised version of this book.

SHIB K. MITRA  
*Joint Director*  
National Council of  
Educational Research and Training

## PREFACE

The 'plus two' stage in the new educational pattern is an important link in the chain of curricular work, wherein it is intended that the student should branch out on the basis of the foundations laid in the first ten years of schooling devoted to general education. Accordingly, it would be necessary at this crucial stage to broaden and deepen the students' base in geography so that those offering it as an elective subject, may develop a keen and intelligent interest in the subject that is so useful in their every-day life as well as in their areas of specialization. Further, being a subject of an interdisciplinary nature, geography helps in the study of allied disciplines, especially botany and zoology among the natural sciences, and economics, political science, sociology and the like among the social sciences.

Against this background the Editorial Board, in collaboration with a large number of teachers and various academic agencies interested in improving the teaching of geography at different levels in an articulated manner, developed a framework of curriculum consisting of systematic geography for two semesters and geography of India for the remaining two semesters.

The present volume on Physical Geography meant to be used in the first semester in Class XI is preceded by two chapters dealing with the nature and scope of geography as a discipline and its place in the world of knowledge. In fact, these two chapters provide an introduction to the entire course spread over four semesters.

Its companion volume deals with Human Geography. The synthesis of the principles discussed in these two volumes and their application would be discernible in the other two volumes, viz., (1) India : A General Geography ; and (2) India : A Regional Geography. The emphasis on the study of India and on regional geography needs no elaboration.

The Editorial Board is also of the view that the study of geography and real appreciation of its nature and methodology remain incomplete if theoretical study is not complemented by practical work in the laboratory and the field. Hence the Board has provided for adequate field and practical work in its course outline and has produced a separate volume in this series, entitled Fieldwork and Laboratory Techniques in Geography.

A workbook in geography for Classes XI and XII is yet another addition in the series introduced by the Editorial Board. This move was widely appreciated by geography teachers.

( viii )

I am grateful to Dr. A. B. Mukerjee who wrote this book, notwithstanding a serious accident he met with. My sincere thanks are also due to Professor C. D. Deshpande who, besides contributing the first two chapters of the book, took pains to go through the manuscript of the book carefully and did his best to render it in as simple a language as possible. I am also indebted to Shri V. S. Chaudhary who rendered the book into Hindi in a very short time. Also, grateful mention may be made of Shri Purushottam who prepared the maps and diagrams included in the book.

My special thanks are due to Smt. Savira Sinha of the National Council of Educational Research and Training who has been responsible for seeing this book through the press. But for her devoted and diligent work the book would not have seen the light of the day in its present form.

Curriculum construction and development of instructional materials are on-going processes, and hence every suggestion from the teachers in the light of their experience would be most welcome. These would be taken into account while bringing out the revised version of this book.

New Delhi  
21 July 1977

MOONIS RAZA  
*Chairman*  
Editorial Board for Geography

# CONTENTS

FOREWORD	<i>Page</i> (v)
PREFACE	<i>(vi)</i>
LIST OF MAPS AND DIAGRAMS	<i>(x)</i>

## UNIT I—GEOGRAPHY AS A DISCIPLINE

### *Chapter*

1. Introducing Higher Geography	3
2. Man and Nature in Geography	13

## UNIT II—GEOMORPHOLOGY

3. Structure of the Earth	23
4. Materials of the Earth's Crust : Rocks and Minerals	33
5. Rocks and Associated Economic Minerals	44
6. Rocks and Associated Landforms	49
7. Soils	56
8. Exogenous Processes in the Evolution of Landforms	66
9. Endogenous Processes in the Evolution of Landforms	82
10. Landforms and their Economic Significance to Man	95

## UNIT III—CLIMATOLOGY

11. Climate and Man	101
12. Composition and Structure of the Atmosphere	104
13. Insolation and Heat Budget	108
14. Distribution of Temperature	114
15. Pressure and Winds	121
16. Air-masses	134
17. Atmospheric Disturbances and Cyclones	139
18. Humidity and Precipitation	143
19. Classification of Climates	151

## UNIT IV—HYDROLOGICAL CYCLE

20. Hydrological Cycle	159
------------------------	-----

## UNIT V—OCEANOGRAPHY

21. Ocean Basins and Submarine Relief	179
22. Ocean Water and Their Circulation	191
23. Marine Flora, Fauna and Deposits	202
24. Marine Resources	211

## LIST OF MAPS AND DIAGRAMS

Fig. 1	Geography as a Discipline	8
Fig. 2	Natural Environment (N.E.)	14
Fig. 3	Interacting Elements of the Biosphere	16
Fig. 4	Total Environment (T.E.)	18
Fig. 5	Longitudinal Wave and Transverse Wave	24
Fig. 6	Wave Propagation	25
Fig. 7	Paths of Wave in the Earth	26
Fig. 8	Wave Travel Curves	26
Fig. 9	Wave Propagation Velocity	27
Fig. 10	The Main Layers of the Earth's Body	28
Fig. 11	Model of Earth's Interior	29
Fig. 12	Variation of Temperature with Depth	31
Fig. 13	Profile of the Earth's Crust	31
Fig. 14	Profile of a Volcano	34
Fig. 15	Four Types of Intrusive Rock Masses	36
Fig. 16	Classification of Igneous Rocks	36
Fig. 17	Sedimentary Rock	38
Fig. 18	Rock Cycle	41
Fig. 19	Rock Hardness and Relief Features	51
Fig. 20	Clay Topography	53
Fig. 21	Generalised Soil Profile	57
Fig. 22	Main Textural Types of Soil	61
Fig. 23	Main Soil Types	63
Fig. 24	Formation of Graded Surface by Aggradation and Degradation	67
Fig. 25	Traction, Saltation, Suspension	70
Fig. 26	Cycle of Erosion	71
Fig. 27	Drainage Patterns	72
Fig. 28	Fluvial Cycle	73
Fig. 29	Niagara Fall	73
Fig. 30	Gradation of a Stream	74
Fig. 31	Landforms of an Alluvial River Flood Plain	74
Fig. 32	Stages of Meandering and Formation of Ox-bow Lake	74
Fig. 33	Alluvial Fan	74
Fig. 34	Alluvial Terraces	75

Fig. 35	Widening of a Valley by Lateral Cutting of a Stream	75
Fig. 36	Braided Stream	76
Fig. 37	Stages in Formation of a Simple Delta	76
Fig. 38	Intermontane Desert	77
Fig. 39	Pedestal Rock	77
Fig. 40	The Erosional Evolution of a Pediment	77
Fig. 41	Glacial Features	78
Fig. 42	Medial and Lateral Moraine	79
Fig. 43	Continental Glacial Features	80
Fig. 44	Epeirogeny and Orogeny	83
Fig. 45	Horizontal Strata and Compressional Force	83
Fig. 46	Valleys in Relation to Structural Formation	84
Fig. 47	Fracture and Fault Plane	84
Fig. 48	Formation of Horst and Graben	85
Fig. 49	Downwarping and Upwarping	86
Fig. 50	Isostatic Movements in Relation to Erosion and Deposition	87
Fig. 51	Sequences in Continental Drift	88
Fig. 52	Continental Drift	89
Fig. 53	Volcano	90
Fig. 54	The Distribution of Volcanoes	91
Fig. 55	Earthquake Belts of the World	92
Fig. 56	Layered Structure of the Atmosphere	105
Fig. 57	Troposphere	105
Fig. 58	Angle of Incidence of Insolation and Area Affected	108
Fig. 59	March of Insolation	110
Fig. 60	Heat Budget	111
Fig. 61	Terrestrial Radiation	112
Fig. 62	Distribution of Temperature on Land and Water in Summer and Winter	115
Fig. 63	January Isotherms	116
Fig. 64	July Isotherms	117
Fig. 65	Low Pressure and High Pressure	122
Fig. 66	January Isobars	124
Fig. 67	July Isobars	125
Fig. 68	Pressure Belts	125
Fig. 69	Relation of Winds to Pressure	126
Fig. 70	Planetary Winds	127
Fig. 71	Origin of the Monsoon According to Flohn	129
Fig. 72	Formation of Föehn and Chinook	130
Fig. 73	Formation of Mistral	131
Fig. 74	Anabatic Winds and Katabatic Winds	132
Fig. 75	Formation of Jet Stream	136
Fig. 76	Cyclone in the Northern Hemisphere	140

Fig. 77	Cold and Warm Air Masses and Fronts	140
Fig. 78	Convectional Rain, Orographic Rain and Frontal Rain	147
Fig. 79	The Mechanism of Falling of Rain Drops	148
Fig. 80	Distribution of Rainfall	149
Fig. 81	Types of Climate	152
Fig. 82	Simple Hydrologic Cycle	159
Fig. 83	The Hydrologic Cycle	160
Fig. 84	A Model of Hydrologic Cycle	161
Fig. 85	Soil Water Balance	164
Fig. 86	Zones of Subsurface Water	164
Fig. 87	Relation of Water Table to Surface and Changes in it	165
Fig. 88	Perched Ground Water	165
Fig. 89	Rise and Fall in Water Table according to Natural Variations in Annual Recharge	166
Fig. 90	Rock Structure and Springs	167
Fig. 91	Formation of Springs	168
Fig. 92	Spring Well, Percolation Well and Aquifer Well	169
Fig. 93	Geological Conditions for Artesian Flow	169
Fig. 94	Formation of Geyser	171
Fig. 95	Stalactite, Stalagmite, and Limestone Column	173
Fig. 96	The Cycle of Carst Erosion	174
Fig. 97	Continental and Oceanic Crust	180
Fig. 98	Topographical Features of the Sea Bottom	181
Fig. 99	Distribution of Continental Rises and Deep Sea Trenches	182
Fig. 100	Pacific Ocean Basin Bed Topography	186
Fig. 101	Atlantic Ocean Basin Bed Topography	187
Fig. 102	Indian Ocean Basin Bed Topography	189
Fig. 103	Distribution of Salinity	194
Fig. 104	Formation of Wave	196
Fig. 105	Wave Attributes	196
Fig. 106	Wave Velocity	197
Fig. 107	Transverse Wave	197
Fig. 108	Ocean Currents	198
Fig. 109	Formation of Tide	199
Fig. 110	Formation of Spring and Neap Tides	200
Fig. 111	The Principal Divisions of Marine Environment	203
Fig. 112	Types of Reefs	208

## UNIT I

# Geography As a Discipline



## CHAPTER I

# Introducing Higher Geography

We began our study of geography at a very early age in school. In fact, from about the age of seven, and that coincided with our leaving home, going to school, visiting the market, calling on our relations in other places and similar activities. In class, we learnt about our home town or village, our district, our state, our country, and the world as a whole. This was done stage by stage, and we studied how man reacts to his environment in different parts of the world. Why some countries are rich and other poor, and how mankind has advanced from its primitive state to modern agro-industrial societies. We also learnt how, if mankind makes a wise use of Nature's gifts, it can live a happy and purposeful life. Geography, thus, makes us aware of our place on the globe, other countries of the world, our relations with them, and provides us

the wisdom to cultivate, a truly civic outlook. It is no wonder that geography, along with history, civics and other social sciences helps us to be better citizens.

Geography continues to make a useful contribution to our knowledge as we proceed to the higher stages of education. The main purpose of this introductory chapter is to explain the role of geography in higher education. Many people think that geography is a school subject only. This is not so. What we have done so far was to get acquainted with the world and its various parts in a progressive manner. It was a popular view that acquiring a general knowledge of the world was the sole purpose of studying geography, because till the present century much that was taught as geography was drawn from the accounts of travellers and explorets.

### Geography as a Description of the Earth

This, of course, was natural. With every advance of mankind, since ancient times, man's world, as he came to know it, has continuously expanded beyond his habitat. From the ancient valley civilizations, growth of maritime commerce and cultural contacts, expeditions to conquer near and distant lands, voyages and discoveries, during ancient and medieval times, brought in a new knowledge of the various parts of the Earth, through the narratives of explorers, conquerors, travellers and traders. The horizons of man's knowledge of the Earth, thus continued to widen.

But there were also some like the Indian, the Greek and the Arab scholars, who tried to understand the Universe around us and the place of our planet within it. Many of them, like Bhaskara-charya, were good astronomers. We have seen how in our study of the size and the shape of the Earth, latitude and longitude, the Solar system, measurement of time, and the like, these scholars laid the foundations of geography as a science.

Thus, it is easy to understand how till the eighteenth century there were scientists—few in number but distinguished—who identified geography with the astronomical phenomena and gave it a strong mathematical character. But the accounts of the newly discovered lands—the New World of the two Americas, Australia and the interior of Africa, and of the maritime routes to the Far East and South-East Asia, became far more fascinating. The European colonial conquests of most of these regions added a practical value to these accounts.

It was during the eighteenth century and the early part of the nineteenth century that such geographical accounts began to be studied in a more systematic manner and for the purpose of a better understanding of the earth and its regions. The German geographers, Humboldt and Ritter, were the pioneers. After them, geography of the nineteenth century followed a pattern of systematic description of the Earth, its continents and lesser regions. Thus *Universal Geographies of the World* were published in Germany, France and Great Britain. The Colonial rule of Great Britain and France in particular made these types of geographies popular, and the early school books in our country, like those of Marsden, Canceron, Morrison and later, L. Dudley Stamp, were fashioned after the general pattern of describing the earth and its regions.

We may say that geography as a description came to be regarded as a study of the man-environment relation, with Ratzel's *Anthropogeographic*. Ratzel argued, or rather over-argued, that man's actions are determined by Nature. This was in 1870's. Following Ratzel, there was a greater awareness of the relationships between man and environment. So, *Geography not only 'described' places but tried also to explain man's response to his natural setting*.

### Is There Anything Else in Geography Beyond Description?

It is often asked, and very properly, whether there is anything else in geography besides descriptions of the earth and its parts? The answer is clearly 'Yes'. Geography is no longer a description or a catalogue of countries, places and the like. What we have studied in geography

earlier was only a starting point, because geography like other sciences has recorded significant progress. It has a point of view of its own, aims and objectives, its methodology and its field of enquiry.

#### *The Point of View.*

It is now generally accepted that geography as a science is a point of view in giving our knowledge of the world we live in. Just as botany is a study of the plant kingdom, zoology of the animal kingdom, geology of the rocks, sociology of our social relations as members of the society, and economics of our economic relationships, geography is the study of an area, and all that features in that area, which is generally known as 'Environment'. The area may be as small as a village or as large as the Earth itself. Our attention is primarily devoted to the surface—the terrain—of the area. We study the surface, its underlying rocks, the mantle of the soil, the hills and valleys, the plants that grow, the animals that move, the weather and the climate and the role that man plays in this setting of Nature. It is from this point of view that geography is called a *Chorological Science* a science which studies areas.

#### *Aims and objectives*

The aims and objectives of geography as a science, thus, become clear. The principal aim of geography is to understand an area as a part of the Earth's surface, in its *totality* as an animated aspect of nature's creation. In studying this totality, it often becomes necessary to study with greater precision one particular aspect that contributes to the totality. Thus we may study, for example, the Rajasthan desert—its natural setting and the human response, by considering all the important natural and

man-made aspects, which distinguish this region from its neighbour. We may also study, more specifically, features like the micro-climatic variations in the Rajasthan desert or the behaviour of ground water in it. The first approach is often termed *regional geography*, and the second, *systematic geography*. It is possible, and indeed desirable, to apply both these approaches.

#### *Methodology and Techniques*

For realising its aims and objectives, the science of geography has its methodology and techniques, which have progressively gained precision and some sophistication. We shall acquaint ourselves only with the major aspects. In the first place, geography heavily depends, as do other sciences, on scientific method and logic. This implies an orderly way of gathering the facts that are relevant, classifying them on the basis of similarities and an effort based on clear reasoning to draw some meaningful inferences. By *techniques* we mean the ways in which the facts are sifted, processed and interpreted. The use of right techniques for a given geographical problem or a situation depends upon the skill of the geographer. Published maps, published statistical information or data, field studies including specially prepared maps, collecting the required data and the like, provide the geographer with his data. But, further, he has to transform and interpret the data so as to make his geographical study meaningful. He does this mainly through (a) cartographic and (b) quantitative methods/techniques.

We should remember, however, that in all this the geographer's attention is restricted to the area and the changes that are taking place. Throughout his study,

he asks himself two important questions : (a) What are the patterns and processes involved in the changes taking place in the area under study, and (b) how does man's effort express itself in the terrain, and what could be the meaning of the pattern, process and human response ? Do they show some commonness ? Do they, in other words, conform to some tendencies or laws ?

In developing this reasoning the geographer uses, what the students of logic term, both *deductive* and *inductive* methods. We shall not go into the details. Deductive implies conclusions arising from a stated premise. Inductive means gathering a set of facts and trying to identify the commonness in the observed patterns and associations. In both cases, we try to set some meaningful inferences and more important we try to test whether our inferences are correct or otherwise. This testing is called empirical testing. As we proceed to learn more about geography, we will come across Christaller's pattern of settlement hierarchy or W M. Davis's 'cycle of erosion'. Air photographs, space photographs and computers have considerably strengthened the tools of the geographer. Thus, the geographers' methodology and techniques have become more precise and capable of meaningful inferences. These practical aspects of gaining direct experience of geographical phenomena can be acquired with the help of the companion volume, *Field and Laboratory Techniques* and other similar books.

#### *Relation to other Sciences*

Geography draws a good deal of its requirements from allied sciences—both Natural and Social—and in its turn

geography makes a useful contribution to them. Thus there is a close relationship between geography and other sciences, also called *disciplines*. Geography, accordingly, has several interdisciplinary areas shared with other sciences.

Some scholars prefer to 'identify this relationship by a classification of natural sciences into *chorological*, whose main concern is with the study of regions or areas, *chronological*, with the study of element of time, and *systematic*, with the study of the Earth phenomena by systems or classifications. Thus, astronomy and geography are chorological sciences, which are linked with each other. History and pre-history are chronological sciences which give geography its dimension of the time element , they help us to understand, for example, how the face of modern India evolved through ancient and medieval times ; or how man evolved biologically from the early *homo* to the *neolithic* man. Physics, Chemistry, botany and zoology are systematic sciences which enable us to study the more precise aspects of man and environment in a region. It must be made clear, however, that this classification serves the purposes of study as useful avenues, but cannot be regarded as a rigid compartment, for almost every science has a component of space, time and subject matter that can be classified.

The increasing association of other sciences has enriched geography both as regards its content and its sub-fields. Geography, for example, has now entered sub-fields like geomorphology, having close links with geology, historical geography with economics, biogeography with botony and zoology. We shall soon acquaint

ourselves with these sub-fields and further specialisations.

In its term, geography has contributed to allied sciences like geology, oceanography, meteorology, geopolitics, climatology and ecological aspects of botany and zoology.

The relations of geography are getting closer and very fruitful with economics, which is increasingly interested in the spatial or regional aspect of man's economic welfare, as for example, identifying which regions of India are rich and which are poor, and why. Environmental conditions in the tribal regions of India is a challenging theme for study by both the sociologist and the geographer. Political boundaries and frontiers is an exciting theme that belong both to political science and geography. In studies like patterns of human behaviour in space (area), the association between psychology and geography is yielding fruitful results.

In our approach to these sciences we should be careful and also critical in judging which aspect of each science has a relevance to geography and accept only as much as is likely to enrich our understanding of a geographical phenomenon or problem. Indeed, in our study, we should try to discriminate "what is geography" and "what is not geography", and integrate our findings of those aspects that are relevant for our purpose. The word 'integration', which has now become current in geographical literature, broadly means combining those factors separately identified (and, perhaps, from the fields of allied sciences) and reading their significance in their composite or synthetic form. We shall take a simple

example of what integration and synthesis mean.

If for a region like the Kashmir Valley, we prepare several maps each showing the distribution of important aspects like a physical map of the bordering Himalayan ranges, the middle 'Karewa' (alluvial) plateaus and the Jhelum and its drainage, temperature and rainfall/snowfall at different stations in the valley, distribution of forests and pastures, distribution of cultivated lands, human settlements, roads and the like, we are identifying our data and its patterns in the valley region. When we superimpose these maps in a proper sequence, (from the physical base to the man-made aspects), we are trying to find out the possible association between these aspects. This is a process of integration or synthesis, and it yields meaningful results. As, for example, we find that there is a close association between the form of the land in the Kashmir valley, its agriculture, human settlements and means of transport.

It is more common to use this approach in geography by drawing upon its sub-fields. Although the example quoted above, is one based on map superimposition and interpretation, it is necessary to remember that there are other methods of integration also, most notably now, with the aid of quantitative methods. It is from this point of view that geography is called "a science of integration or synthesis".

### **Sub-fields and specialisation in Geography**

A hallmark of the progress that science makes is the sub-fields and specialisations it develops. Modern Geography is no exception, Geography has two distinct

sub-fields—*Physical and Human*.

On the basis of their origin geographical elements of an area can be classified into broad groups : the natural or physical and the human, that is, man-made or influenced by man. The natural features are those which are creations of Nature, independently of man, like mountains, rivers, virgin vegetation, animal life and the like. The human or man-made features are those created by human groups in their efforts to live in their habitat with ease and security. Agricultural fields, villages, factories and roads, are some examples. As they express the culture of human groups, they are usually, called cultural features. But, in addition, there are some aspects which are not visible expressions, and yet materially influence human action in environment.

These largely belong to the realm of thought. Our thinking, perception, and reasoning, our capacity to absorb knowledge, our view of life, as expressed often through our religion and education, all these are non-material elements, which need to be taken into account. Some of them do express themselves in visible forms like a school building or a religious place, but most of them make a powerful impact on human behaviour in space. The choice of a place to locate an industry and the journey to work (from home to the place of work) in a city, may be cited as examples to show the nature of this impact.

We need hardly warn ourselves that Physical and Human are two convenient divisions made by us for understanding Nature better. Nature represents a unity in its existence (Fig. 1).

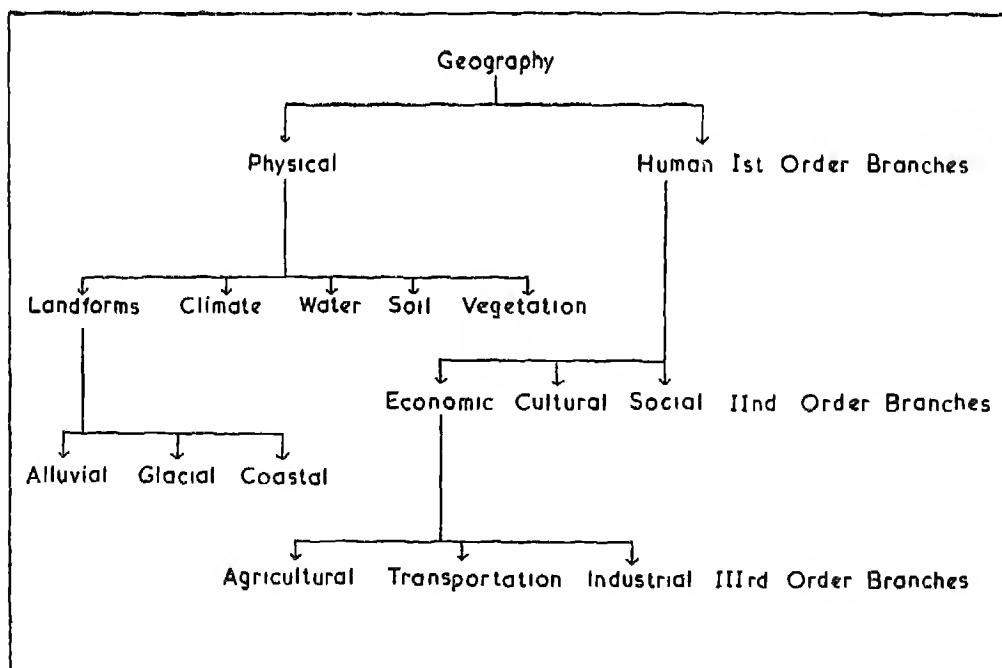


Fig. 1. Geography as a Discipline

### *Sub-fields of Physical Geography*

*Geomorphology*, the science which studies landforms is a rapidly emerging science to which important contributions have been made by geology, geography and climatology. In regional geography, the understanding of the terrain and its main and detailed features is indispensable, and as such geomorphology provides the base for geography.

*Climatology*, though a science almost independent by itself, is also a necessary part of physical geography, in that it provides our understanding of the processes involved in the shell of the atmosphere that surrounds the globe. *Hydrology*, an emerging science, helps us to grasp the processes whereby water plays its role in nature through oceans, rivers, glaciers, etc., and in sustaining its life forms. *Soil geography*, which is a part of pedology, deals with the kinds of soils, their evolution, regional distribution and their role in land use.

### *Sub-fields of Human Geography*

The main sub-fields of human geography are : *Cultural Geography* which deals with the cultural aspects of different human groups. Cultural aspects include man's habitat, clothing, food, shelter, skills, tools, language, religions, social organisation and his outlook. As civilisation advances, all these and other aspects present a variegated form both in function and spatial distribution. Some geographers prefer to call this sub-field *Social geography*. *Economic geography*, a rapidly developing sub-field, concerns itself with man's activities in improving his material well-being through economic production, exchange distribution and consumption of useful goods and services,

that human groups and their members need. How these activities develop in a region, through man's use of the region's natural resources and how they are either locally consumed or sent out of the region to some other region in exchange, are the main concerns in economic geography.

*Population geography* mainly deals with those biological and cultural characteristics of human groups which strengthen or weaken the groups in their effort to develop the resources of their region and their capacity to live in comfort in their habitat. Human groups in their absolute numbers, birth rates and death rates, age-sex composition, levels of nutrition and literacy, may be said to be the principal aspects of this study with reference to their spatial distribution of the various forms in which human groups settle in a region. The principal forms are house types and settlements, rural and urban, ranging from a hamlet to a modern metropolitan city. *Historical Geography* seeks to build up the geographical picture of a region or area, as it evolved from time to time in its past. It gives us important clues in understanding the region as it is at present. *Political Geography* aims at analysing political and administrative decisions or choices of organised human groups in their spatial setting. Relations between independent states, frontiers, boundaries, federalism, local government and regional planning are some of its principal concerns.

### **Some further specialisations in geography**

So intense has been the recent research in geography that each of its many sub-fields has led to further specialisations.

We may mention only a few to understand this development. In geography, for example, *glacial*, *coastal*, *climatic* and *anthropogenetic* (i.e., landforms influenced by man's action) geomorphologies are making a significant contribution. Micro-climatology is another example, on the physical side of geography. On the human side, there has been a powerful emergence of specialisations in economic geography, in the form of *agricultural*, *industrial*, and *transport* geographies. *Medical geography* is a specialisation which has emerged from biological aspects of interaction of man in his environment.

It is possible to view these sub-fields and specialisations in an orderly arrangement that enables us to recognise their place and role in the science of geography. Physical and Human are the main branches, sub-fields like geomorphology or economic geography are of second order. Glacial geomorphology or agricultural geography belong to the third order.

*Regional geography*: We now come to an important aspect of geography that is not a branch or sub-field, but rather a counterpart of these aspects. It is a study of a region at different scales—continents, countries, regions, local areas, etc.,—in all its geographical aspects. Identifying the main geographical characteristics of a region, the interplay between man and nature and its expressions on land and reactions on man and nature's resources, delimitation of geographical regions, status and relations between regions of different size and regional planning, are some of the principal concerns of Regional Geography. In fact, Regional Geography is a summation of the findings of other sub-fields and specialisations in geography

that are relevant to the area under study. We shall make this clear by examining the relation of regional geography to other branches of geography which are usually termed together as systematic geography.

#### *Systematic Geography and Regional Geography*

In identifying the branches and sub-fields of geography and what Regional Geography implies, we can see that there are two ways of studying a geographical phenomenon. One way is to select one geographical factor such as climate and study its world-wide distribution, recognise the climatic regions over the globe and go into the detailed regional climatic types and sub-types. Such a study of climate can be done at any scale of the area : India and its climatic regions, the climatic regions of Rajasthan with its north-western region of arid climate and the south-eastern semi-arid climate of the Aravallies, the highlands and surrounding sandy plain of the Luni Basin, both of which are a part of south-western Rajasthan. This study of a specific geographical factor is known as the systematic approach in geography.

#### *The content and methods of Regional Geography*

Regional Geography, on the other hand, considers the area as a whole first and aims at identifying those geographical factors or components which in their unison create the distinct character of the region ; in doing so, it examines the man-environment relationship with the constant change that is taking place within it. This is done by integrating the findings available as regards individual geographical phenomenon. It will be readily seen that systematic geography contributes its

findings and regional geography presents an integrated picture of the region as a whole. It also compares the region under study and its relationship with neighbouring ones. This aspect is called 'space-relationship'. Further, the study of regional geography implies demarcation of regions and sub-regions within the study region. The process of identifying various regions is often called *regionalisation*. This aspect also includes the study of the status, that is, the place of various regions, sub-regions, even smaller regions, and the linkages between them in their interactions. It is usual to call this procedure a classification of regions and identifying the *regional hierarchy*.

We may briefly illustrate these concepts and procedures by continuing our example of Rajasthan. Broadly, the most prominent geographical factors operating in the area delimited by the boundary of the State are its rocky and sandy terrain, its soils, more importantly its arid climate, the expanses of desert interspersed by scrubby grasslands in low-lying basins and occasional strips of agricultural land supported by local wells. The density of the population is low and has settled in small widely distributed villages and hamlets, many of which are the homes of cattle-rearing nomadic communities. Communications are few and far between and most of them connect the ancient towns of Rajasthan like Jaipur and Jodhpur. It may be seen that human life and the pattern of living are highly influenced by its arid and semi-arid climate. Altogether, the picture of man-environment relations is one of man's strenuous effort to improve his economic status and his living, in an environment which is harsh. We build

thus regional picture of ours with the help of maps, statistical data and other sources. We aim at *integration* of our material so gathered to understand Rajasthan as a geographical region.

We further try to identify sub-regions and their smaller regions, on the basis of relevant factors. Thus, Rajasthan may be divided into the arid north-western region and the partly forested, hilly region of the south-east. The south-eastern region can be further classified into (a) the Narmada hills, (b) the Udaipur hill complex, (c) the Luni border lands, and (d) the Aravalli hill complex, on the basis of terrain and land use characteristics. Each of these smaller regions can be further broken down into still smaller geographical regions.

Here, we should note that the technique of identifying and demarcating regions, or regionalisation, has become more precise and objective for time. Geographers used to classify regions on the basis of their intimate understanding of the region and on the basis of factors which they regarded as most relevant at each stage in classification. Nowadays, with the use of refined cartographical and statistical techniques, it is possible to demarcate regions more objectively and weigh their place in the regional hierarchy, with a greater precision. Such exercises are useful not only to gain a good insight into the regional geography of the land, but also for regional planning and development. We now have some good studies of our country as a whole and in greater detail for some of its regions like South India and some districts like Karnal in Haryana.

### The field of geography

We thus, see that geography has a useful contribution to make in our study of the Earth and its various regions. We come across several well known definitions of geography—'as a science of places', a study of the Earth as the home of mankind". Each of these definitions may not convey the entire content of geography, though it does emphasise one or more aspects. But, we can always remind ourselves that the field of geography contains an area,

its geographical envelope and the constant change that is taking place in the natural and human phenomena. Our study of geography, therefore, should be oriented towards the *area*, the *relevant aspects*, the *interactions* in the phenomena, the *spatial patterns and processes*, their changes, and above all what these changes imply in terms of man and his well being.

In the next chapter, we shall deal with the theme that is basic to geography-man and nature or man-environment relations.



## CHAPTER 2

### Man and Nature in Geography

The relationship between Man and Nature is such a basic theme in geography that it merits a detailed discussion. Initially, it would be worth while to recall the familiar statements that Nature has ordained or determined man's life and actions or about man's conquest of Nature. We realise that these traditional views of the man-environment relationship, are exaggerations. It is difficult to accept either of them because our experience and facts do not lend support to these views. To justify the first view, it used to be argued that man in the tropics with its hot and moist climate will always remain lethargic and backward, because it has been ordained by nature. Our past civilisation and our present economic progress as an agro-industrial nation does not support this view. Examples to show

the so-called conquest of Nature by man are many and all too familiar. Man's progress in science and technology is revealed by modern industry, the creation of metropolitan cities, conquest of distances through better means of transport and communications the latest example of which is man's landing on the moon. But, can we really say that man has conquered nature when we still have to face such calamities as earthquakes and floods? Such exaggerated views are mainly due to an incorrect assessment of the man-nature relationship. The relationship, far from being conflicting, is one of cooperation, and Man in Nature is a more faithful description of the man-environment relationship. Man's very existence on the earth depends upon the terrain it provides and the bounties it offers. As a leading

geographer has stated "Nature provided the stage, and it is for man to act on it." (Vidal de la Blache).

### Understanding the Environment

For our purpose before trying to understand the man and nature or the man and environment relationship it is necessary to know what environment means. In geography, when we talk of nature, we often equate it with environment though the two concepts are not precisely the same. When we refer to nature we mean those creations in which man finds himself : the terrain, the landforms, the climate, the vegetation, the animal life and their mutual association. These we see as features or elements of a natural landscape. These are creations not made by man, but by forces that are external to him. When we refer to environment, we emphasise the interrelationships and influences that nature's different constituents exert on each other and the sum total of the effect produced (Fig. 2).

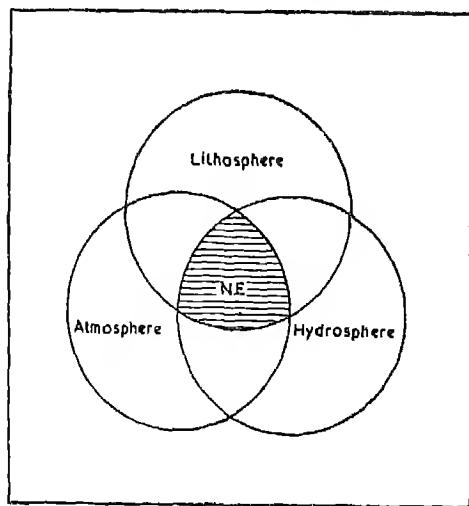


Fig. 2. Natural Environment

Thus, we speak of an equatorial environment or a desert environment. In an equatorial environment, rocks rot and lateritic soils are developed ; there is a luxuriant plant growth, with its typical form, under hot and moist climatic conditions. A typical example of the second type of environment is the Rajasthan desert with its bare rocky landforms, sandy soils, and stunted scrub and coarse grass, supporting grazing animals like the camel and the sheep. The mutual relationship between sandy soils, dry climate, scrub and animal life in the Rajasthan desert is seen in their adaptation and mutual dependence. In an earlier study of geography we have known something of adaptation, and here we shall go into some details of mutual dependence. Poor and sandy soils and arid climate can support only a scrub vegetation which in its turn can support hardy animal types, and the animals support human groups who can tend them as well as feed on them ; these are our nomadic shepherds of Rajasthan.

In addition to these sequential links between each of these, there are direct links like the one between landform and man ; an oasis with a good soil and local irrigation helps man to cultivate the land ; man regards springs, wells and tanks, as vital to his living. This totality of influence in any given area may be called, for our purpose, environment. To give a parallel, nature offers the stage—that is the area, as well as the actors on the stage ; the principal actors are the landforms, climate, plant and animal life, they mutually interact to create the environment and in that very process they—unlike the actors—get influenced ; in their form, appearance

and functions, and even in the case of living beings their mental reactions. Only in the case of higher animals like monkeys some processes of thought may be seen, but the most thinking of them is man.

### Natural and human environment

With every advance in civilization, man has become more and more the dominant actor. That is why some scientists prefer to identify the natural environment as the humanised or the human environment. The former is created by non-human agencies while the latter is influenced by man, in an ever increasing measure, almost to the extent of creating a totally man-made environment as we see in metropolitan cities. We must, however, remember that the distinction between the natural and the human environment serves as a useful guideline for understanding the environment. Environment, as a reality, is one, and when man enters it, he not only influences it, but in turn is influenced by it too, according to his wisdom and ability to take advantage of nature's resources.

### Ecosystems

There is another interesting aspect of nature and environment. In a given area or a region, each of the constituents, broadly identified as geographical factors and their components in all their vast numbers, have a life-cycle. They are born, grow to maturity, then decay and die. Landforms, plants and animal life have this cycle; only the rate of change is different<sup>1</sup>. In plant and animal life, the changes take place over short periods. Plant communities for example, grow in

association with each other, and arrive at a final stage in their growth, after which there is no change in their composition as a community, though their individual members may grow and die. This stage is called ecological balance or climax (or *homeostatis*—a Greek word). In a more complex manner this is what happens in the growth of plant and animal communities all living together in the area. The energy for their growth is ultimately derived from the sun and finds its way through innumerable components of nature and continuously operates as *energy cycle*. This expression of the energy cycle through various forms on the surface of the earth is known as an *ecosystem*. The concept of ecosystem helps us in understanding the mutual interdependence of the components of nature, especially in its biological aspects.

### Ecosystem and environment

There is a close relationship between the ecosystem and the environment. Just as an ecosystem advances to its climax it can have a reversal also. Overgrazing and destruction of the forest cover has turned many green lands into bleak and barren lands. Palestine, in the Biblical days, was 'land of milk and honey', today, because of overgrazing, it is, for the most part, a desert. We have many examples of such reversals in the ecosystem. Such reversals are caused mainly by human interference in the ecosystem. The more persistent effect of the changes in an ecosystem is felt in the changes in the environment. There are extensive lateritic plateaus in the Konkan lands of our country. Once, these were covered with rich forests and good animal life. Local communities cleared these forests to obtain timber and

---

1. Even climates change over a long period, but we do not know whether there is a cycle of life in them

fuel as well as to till the cleared land. The soil became poor and dry, these lands have now become barren and practically nothing can grow on them. The earlier environment of a moist landscape has been changed into a dry one.

### Man as ecological dominant

This brings out the important issue that man, through his skills and tools, has increasingly become a dominant factor in ecosystem and the environment. He has domesticated animals like the horse, the ox and the sheep, for his use. He has tilled the ground and raised selected plants as crops. These domesticated plants and animals (termed *cultigens*) have enabled him further to destroy forests and alter the landscape of a region as well as its ecosystem. Later, with the acquisition of greater skills, he has built roads and other forms of transport, towns, ports and industrial cities. Thus in modern times man has become a dominant ecological agent, and has used the earth's

resources to his immediate advantage, but in doing so, he is altering the ecosystems and environments which from the long-term point of view, are likely to be disastrous for him and his habitat on the Earth. Pollution of the air, water and the seas that is going on today is only a forewarning.

### Man-environment relationship as an interacting system,

The role of man in his environment as discussed above can be viewed more clearly if we see it as an interacting system in which man is also one of the participants. But being a dominant one, his role has become increasingly important. Man, since the dawn of human history, has realised his role in nature, more unconsciously than consciously. Like other life forms on the Earth, he began with the common process of adaptation to nature. Where he differs from other life forms is in his adaptation with a purpose and a well directed effort. He began to think, reflect, and acquire knowledge and skills that would add to his living, comfort and safety. The essence of human civilisation lies in this reaction of man to nature.

### Human response .

The man and nature or 'Man in Nature' relationship is unique in the fact that man does not respond to the stimuli generated by nature through his instincts alone. His behaviour towards nature or with reference to its stimuli depends very largely on the culture he has inherited. By culture we broadly mean the skills he has acquired, the way he makes use of his skills, his customs, manners and social relationships and above all his knowledge, wisdom and

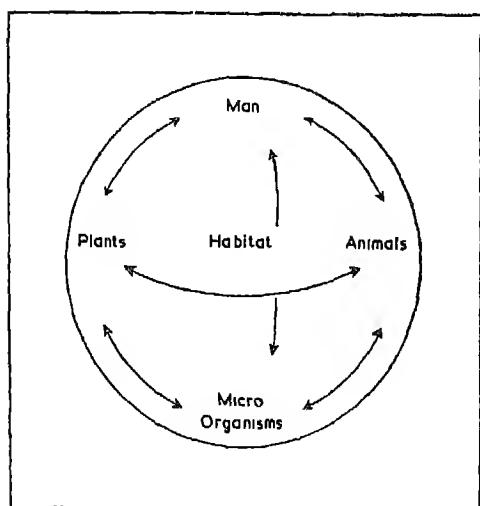


Fig. 3. Interacting Elements of Biosphere

outlook. All these elements of culture are gathered by him as a member of the human society, through ages since the dawn of civilisation.

#### **Spatial variations in response .**

It should be noted, however that no two groups in mankind respond to nature in the same way. There are variations from one part of the world to another. This relationship has its origin within an interacting system between Man and Nature, and it is dynamic, complex and not always to the advantage of man, as will be clear from two examples.

#### **Ancient Greece and modern Europe :**

The civilisation of ancient Greece is known for its cultural advancement. The people tilled their lands well, produced beautiful handicrafts, devoted their leisure usefully and produced marvellous pieces of art and architecture. Their contribution to literature was great and their thinkers like Plato and Aristotle exert their influence even today. But after a period, the Greek City States—small and independent republics as they were—indulged in mutual warfare and that mainly caused the decline of the Greek civilisation.

The present-day Western Civilisation owes a great deal to the ancient Greek and Roman civilisations. But the European communities responded to nature more vigorously and with a spirit of adventure. They charted the unknown seas, discovered new lands, conquered and colonised many, invented the steam engine and ushered in the age of modern industry. Their progress in education, science and technology has been so remarkable that most of the European societies both in Europe and the New

World are rich, active and are today the leaders of the destinies of mankind. But they have had as we know, their mutual wars mainly due to political rivalries and exploitation of colonies. With their advanced technology, they are now able to send artificial satellites round the earth and space-ships to the moon. Their success in handling nuclear power has produced useful energy both through nuclear electricity power stations and the forms of nuclear bombs, the former for the benefit of mankind and the latter holding a potential for its destruction. These two examples of interaction are enough to show that interaction leads to man's progress and can also lead to disaster.

We call this relationship an interacting system because every change caused by man in his ecosystem leads to other repercussions entailing changes in other elements of the ecosystem and thereby in the environment. We can, for example, trace this interaction through the 'food chain' in which man plays an important role. This interaction, therefore, shows some order and pattern which is more easy to identify as a part of a system. Several aspects of this interaction can be studied in a methodical way, with observation, experiments, mapping and interpretation. The development of sub-fields and specialisations in Physical and Human Geography are but attempts to trace this interaction with greater precision and understanding.

#### **Interaction in space and through time .**

It is possible to study this interaction both with reference to the present day world and its various regions and with reference to the historical past. Indeed

both these approaches are complementary and help us to understand the interaction better. For example, our country even today is an agro-industrial nation. Great Britain and Japan are highly industrialised nations, while the U.S.S.R. and the U.S.A. have developed their resources so well that they are regarded as the most powerful nations of the world. Let us take another example from a geographical point of view. In western Europe interaction between man and nature is strong and purposeful, while in a major part of the continent of Africa, it is weak with nature dominating. We have already studied the Eskimos, the communities of the Sahara desert and those of the Equatorial regions. The examples given above relate to studies of present-day interactions in different parts of the world. In other words they are spatial studies with reference to the space or the surface of the earth as it is today.

We can now take the example of our own country and see how this interaction can be studied through time as well. The early Aryans reached India as cattle-rearing nomads. Soon they became agricultural communities. In recent times we have progressed both in agriculture and modern industry. Here we study the historical evolution of India and the Indian Society. This approach to study with reference to the time element is called the *temporal* approach. We should remember, however, that in geography even while studying with reference to time, we cannot lose sight of space. The aim of geography, in this context, is to study the interaction in space with reference to a particular period of time.

#### Total environment.

We may now summarise our findings

relating to the environment and man's role in it. In the natural environment there are three already familiar domains—the Lithosphere, the Hydrosphere and the Atmosphere. To these we may now add the Biosphere the realm of all living forms, of the plant and the animal kingdoms. It, of course, includes man. It is the thin life-bearing layer above the Earth's surface where the different spheres act and interact to produce and sustain all living forms. This life layer nearly extends vertically from the deepest oceans to the higher life-bearing layers of the atmosphere above. It has a range of a few km. Both vertically as well as horizontally the biosphere has wide variations. The importance of identifying the biosphere is two-fold, it shows the place of man in nature's life forms and how as a life form he is becoming increasingly dominant.

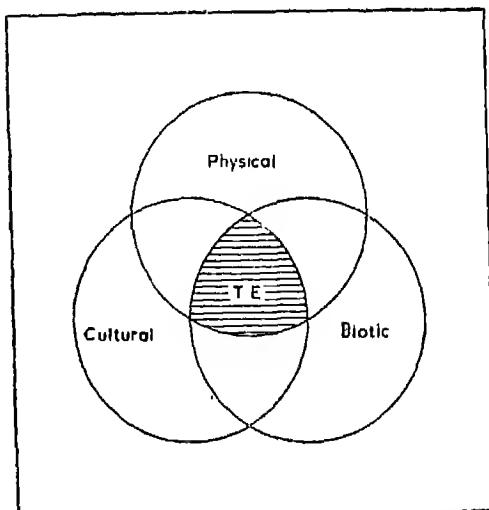


Fig. 4. Total Environment

Finally, it would be seen that despite of man's dominance, the environment

operates as a whole. Our earlier distinction between the natural and the human is only for understanding the environment as a whole. It should also make us realise the way in which man is playing a constructive and a destructive role in his environment and how the resources of the Earth could be wisely used, conserved, and wherever possible replenished. This is what geography as a science teaches us.

These first two chapters are meant to serve as an introduction to the study of geography in classes XI and XII. The rest of this book analyses the main aspects of Physical Geography. Its counterpart, Human Geography, is the Subject of a companion volume. The techniques in

the study of geography in the field and with the aid of statistical and other data and maps are presented in 'Field work and Laboratory Techniques in Geography'. Finally the way in which the principles that we learn and the techniques we acquire while studying higher geography help us to understand a part of the Earth's surface and the problems of its people form the subject of the fourth text book. This is a book on India and has been divided into two parts. India—A General Geography, and India—A Regional Geography. All these books are accompanied by work books covering the entire course spread over four semesters.





## **UNIT II**

# **Geomorphology**



## CHAPTER 3

# Structure of the Earth

The study of the structure of the earth focusses on its layered structure, and the variations in the density and temperature, at various depths. These temperature variations are both a cause and an effect of the layered structure.

There are at least five important aspects in the study of the structure of the earth :

- (i) There are two forces, exogenic and endogenic, which mould the earth's surface and create land forms. The energy of endogenic forces is derived from the earth's body.
- (ii) A large part of the earth's surface is composed of rocks derived from within the earth's body. The upper crust consists mostly of silicates.
- (iii) The variations in the surface

material depend on the variations in the properties of the layers from which these have been derived. For example, the acidic rocks containing a larger proportion of silica form granite and quartz which largely constitute the crust. Similarly, the basic rocks containing a lesser proportion of silica form basalt, gabbro, and dolerite which comprise the lower crust and the upper mantle.

- (iv) The earthquake foci, the compressional orogenic forces which create mountains, tensional rifts which create rift valleys, and fault forces which cause the displacement of the broken crustal parts originate in the lower crust and the upper mantle.

(v) The important geophysical theories, the formation of mountains, and oceans, isostasy, earth-movements, and the drifting of continents are based on the concept of the layered structure and the conditions prevailing in each of the layers.

The earth's body comprises several layers, which are like shells resting one *above* the other. These layers are distinguished by their physical and chemical properties, particularly, their thickness, depth, density, temperature, metallic content, and rocks.

The earth began as a nebulous gaseous and liquid body. It gradually cooled and solidified. During these processes the heavier material sank down and the lighter material floated up. Thus, according to the density of the material comprising the liquid mass, which was a mixture of materials having different densities, the different materials became separated and formed layers of different densities.

Thus, the three main layers or shells constituting the earth's body—the crust, the mantle, and the core,—are mainly the density layers.

The question that now arises is what are

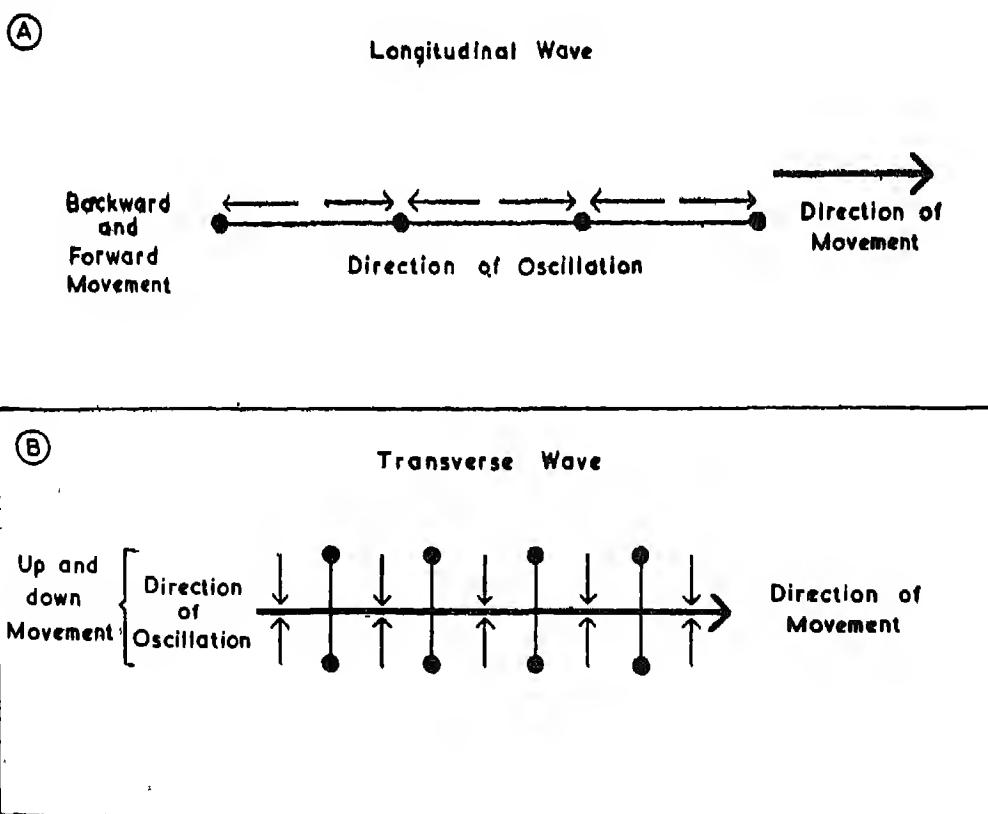


Fig. 5. Longitudinal Wave And Transverse Wave

the sources of knowledge of the layered structure. Direct observation is not possible because of the tremendously high temperatures in the deep interiors and because of the depths of upto 6400 kms. As the deepest mines go only as deep as 3 kms. direct observation is limited only to these depths. Hence, all the important sources of data on the layered structure are indirect and are logically derived and inferred from other evidences. The most important source of data is seismology which is the science of earthquakes. There are various types of earthquakes and earthquake waves. The nature of these earthquake waves and their travel speeds reveal the internal layered structure of the earth. Additional data are supplied by the paths of travel. The laboratory study of the rocks extracted from the surface and from various depths also provide data on the density of the outer rock layers in the earth's crust.

Earthquake waves have three basic properties : type, propagation velocity, and path of travel. These properties are affected by both the structure and the properties of the layers.

There are also three types of waves : longitudinal, transverse, and surface, or long. All these waves originate from a point, termed *focus*, within the body of the earth and are recorded by seismographs.

The longitudinal waves are similar to sound waves and travel in solid, liquid, and gaseous media. These are also termed *P* (Primary). In these waves the direction of movement and the direction of oscillation of the particles are the same (Fig. 5).

The transverse waves, usually termed *S* (Secondary) or sheer waves travel only in

solid media. These waves are slow in motion and not so well developed in bodies which change their shape easily. Their direction of travel is at right angles to the direction of oscillation.

The surface waves, usually termed *R*, (Rayleigh) waves move along the boundaries between solid, liquid and gaseous media. Their intensity decreases rapidly with depth, but with low velocity they may penetrate deep into the earth's mantle over a long period of time.

The surface waves are generally set up on the earth's surface (Fig. 6).

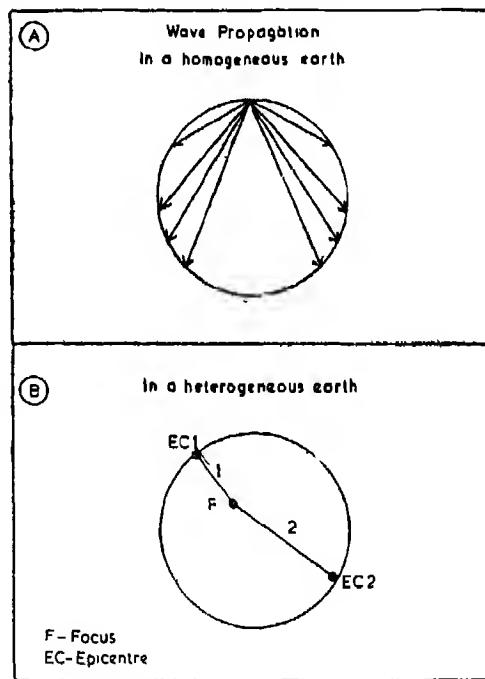


Fig. 6. Wave Propagation

In an earth composed of homogeneous material the propagation velocity and the path of propagation of the earthquake waves are characterized respectively by uniformity at all places and straightness. In

such a hypothetical case there should be a simple relationship between the time during which the wave travels and the distance along the earth's surface. With an increase in distance travel time also registers an increase (Fig. 7).

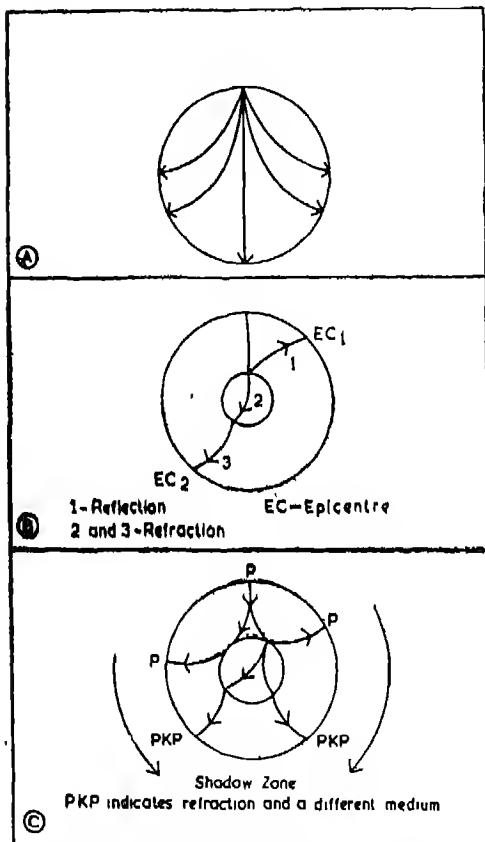


Fig. 7. Paths of Wave in the earth

Actual observations have shown that the actual and theoretical relationships between the travel time of the earthquake waves and the distance along the earth's surface are different. The waves reach the distant places sooner suggesting that the interior of the earth is heterogeneous. The waves arriving at more distant stations

travel faster (Fig. 7 A). In Fig. 7 B, wave 2 reaches EC<sub>2</sub> earlier than wave 1 reaches EC<sub>1</sub>. Hence, the wave which travels through a greater depth has a higher propagation velocity. The velocity of wave propagation increases with the depth. This suggests changes in the physical properties of the earth's interior. For example, the velocities of propagation at depths of 50 kms. and 2900 kms. are respectively, 8 ms/sec. and 13.5 kms./sec (Fig. 8).

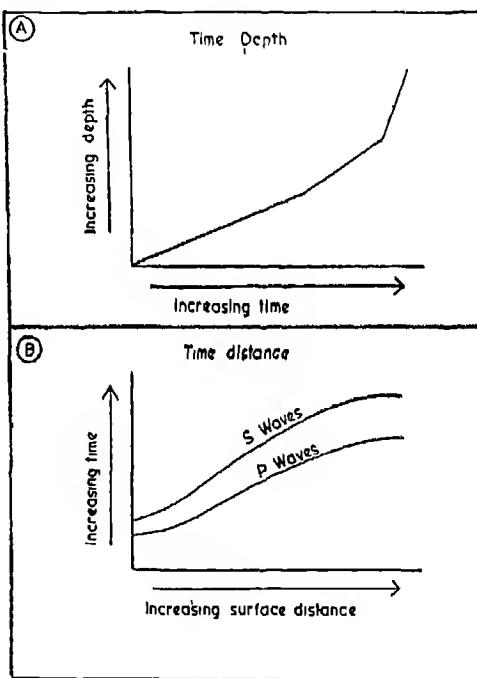


Fig. 8. Wave travel curves

In the real earth the paths of waves are curved suggesting that the interior comprises heterogeneous material. Because the material through which the waves are moving is heterogeneous they are refracted and become curved. There is also an increase in the velocity of wave propagation.

The paths are convex towards the centre of the earth (Fig. 7 A). After reaching a certain depth the wave returns to the surface. At the surface it is partially reflected and travels back into the earth. There are several movements between the surface and the interior.

Both  $P$  and  $S$  waves are reflected and refracted on striking a boundary between layers of different properties (Fig. 7 B & C). Reflection and refraction produce phases. Many phases are recorded by the seismographs. The  $S$  waves cannot travel through liquid and have never been observed in the core. Hence, the core is considered liquid. The rigidity of the material in the core is zero, which is the characteristic of a liquid.

The complex layered structure is inferred from the following observations :

- (i) a large number of the paths of propagation,
- (ii) reflection and refraction suffered by the waves,
- (iii) phases recorded by the seismograph,
- (iv) shadow zone on the earth's surface where  $P$  waves do not emerge suggesting the presence of both core and outer core.

In the shadow zone PKP waves appear. These waves start from the surface or near it as  $P$  waves, travel down to the boundary of the core, suffer both reflection and refraction and emerge on the surface, the

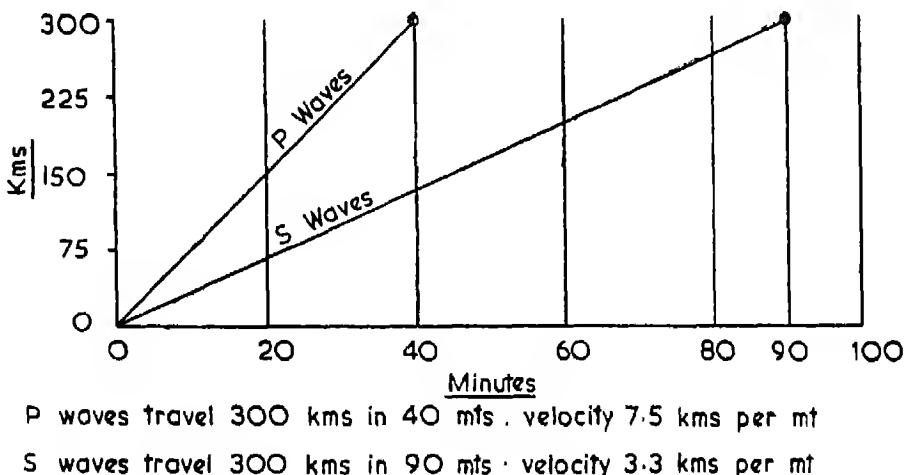


Fig. 9. Wave Propagation Velocity

former as *P*, and the latter as *PKP* waves. The refraction suffered while moving through a different medium suggests the presence of the core (Fig. 7).

There are two types of travel curves : (1) time-depth and (ii) time-distance (Fig. 8 A and Fig. 8 B). The times of arrival

of the various types of pulses and the waves generated by an earthquake can be determined on the seismographs located at various stations. From these times of arrival, travel-time curves are constructed. These curves are also known as hodographs. The curve reveals the relationship

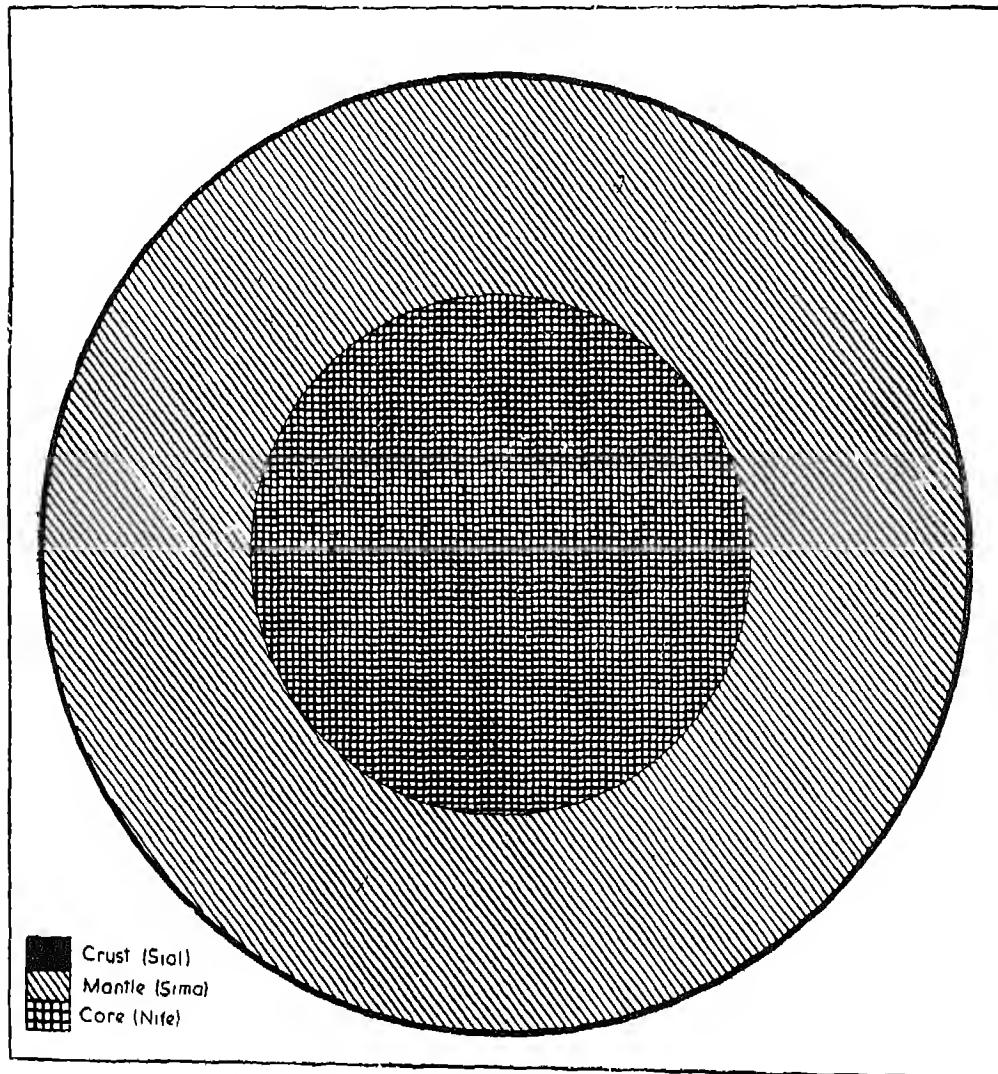


Fig. 10. The main layers of earth's body

between the time in which a wave travels between the seismic focus and a given point, and the distance it travels between them. It enables us to calculate the velocity at any depth within the earth. Fig. 8 B and Fig. 9 show that at any given point on the curves the *P* waves are faster than the *S* waves. For example, the *P* waves take about  $7\frac{1}{2}$  mts. and the *S* waves about  $12\frac{1}{2}$  mts. to cover a distance of 4000 kms. from the place of origin (Fig 9).

Another type of curve, termed velocity-depth curve, shows the relationship bet-

ween the velocity of propagation and the depth at which the wave is moving. The curve provides the initial data from which much of our knowledge of the interior of the earth is derived.

The interpretation of the first two curves suggests the following aspects of the layered structure of the earth (Fig. 10).

- (i) the three segments separated by two sharp breaks in Fig. 8 A represent three velocities, three media having different properties, and therefore three layers.

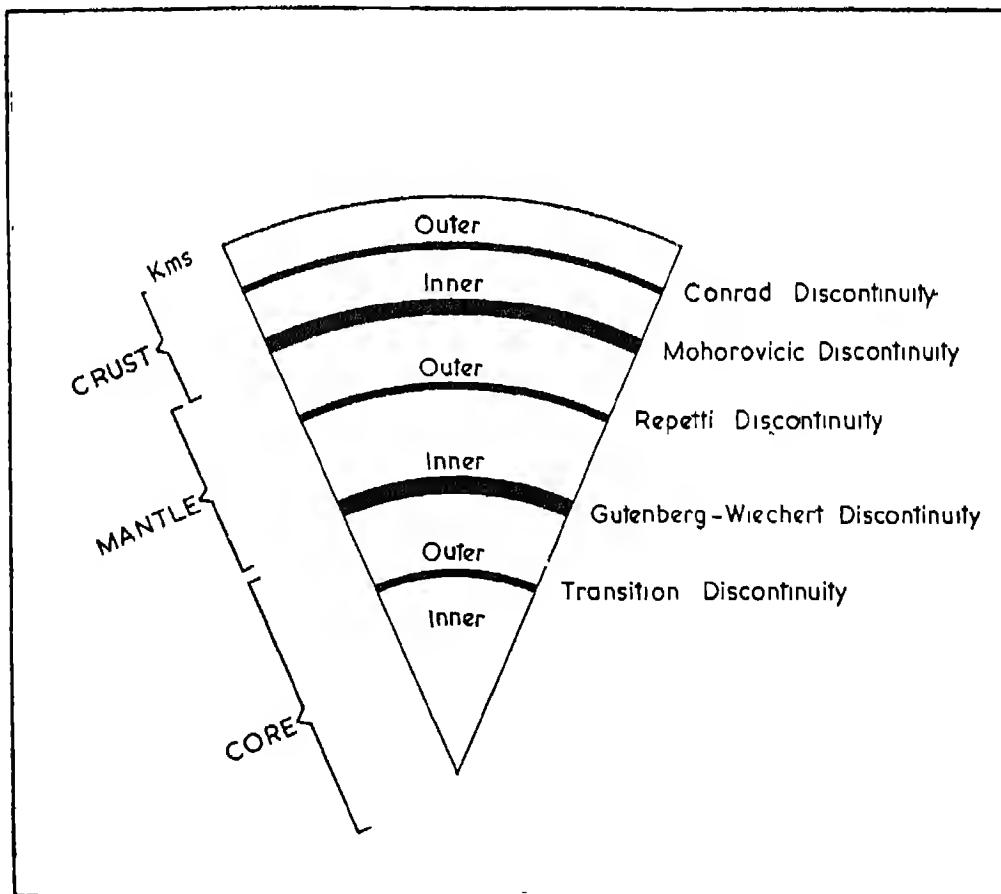


Fig. 11. Model of earth's interior

- (ii) the crust is composed of heterogeneous rocks.
- (iii) below the crust to a depth of 3800 kms. there is an uniformity of material.
- (iv) the core with a radius of about 2600 kms. has radically different properties.
- (v) the central nucleus is fluid but below the crust the material is neither wholly solid nor wholly liquid. It is highly rigid to small stresses of longer duration.
- (vi) the  $P$  wave's continuous acceleration with increasing distance suggests changes in the properties of media.

Changes in the speeds of  $P$  waves at different depths suggest that there are two major, three second-order, and one third-order discontinuities which separate the different layers. The two major or first-order discontinuities separate the earth's body into crust, mantle, and core. Between the mantle and the crust is located a very significant boundary termed *Mohorovicic Discontinuity* or *Moho* (Fig. 11).

There are at least four causes for the formation of the discontinuities in the earth : (1) changes in the chemical composition of materials ; (2) changes in the phase of a given material ; (3) solid, liquid, viscous differences in the silica content within 100 km. of the surface ; (4) changes in the mineral phases which result in changes in the elastic properties of the material.

Earlier, the following were regarded as the main layers :

Layer	Thickness	Density	Modern Equivalent
Outer Sial*	60 kms.	2.75 to 2.90	Crust
Inner Silicate Mantel	1140 kms	3.10 to 4.75	
Zone of Mixed Metals and Silicates	1700 kms.	4.75 to 5.00	Mantle
Metallic Nucleus (NiFe)	4671 kms.	4.75 to 5.00	core.

\* *Sial* refers to a combination of silica (Si) and aluminium (al), sima to silica (Si) and magnesium (ma), and nife to nickel (ni) and ferrum (fe).

#### Density within the Earth

The mean density of the earth is 5.53 ; of the core 17.2, of the mantle 5.68, and of the crust 2.7. On the basis of the density of the different shells along depth, three are major layers.

#### Temperature of the Earth's Interior

In the earth's body there is an increase of temperature with depth. The average rate of increase is about  $1^{\circ}\text{C}$  per 30 metres of depth, but this gradient is highly variable. At the average gradient the theoretically expected temperature at the centre of the earth should be  $2,00,000^{\circ}\text{C}$  but actually it is much less than this level. This is because upto a depth of 100 kms. the increase is of  $12^{\circ}\text{C}$  per km. ; from 100 to 300 kms. depth it is  $2^{\circ}\text{C}$  per km., and below 300 kms. it is only  $1^{\circ}\text{C}$  per km. The temperature of the core is less than  $2000^{\circ}\text{C}$  (Fig. 12).

There are three major sources of heat :— (1) of the earth's interior, (2) radioactivity, (3) the original temperature of the material of which the earth is made, and (4) the heat of aggradation. Chemical reactions within the earth and compression, tension, and shearing of rocks

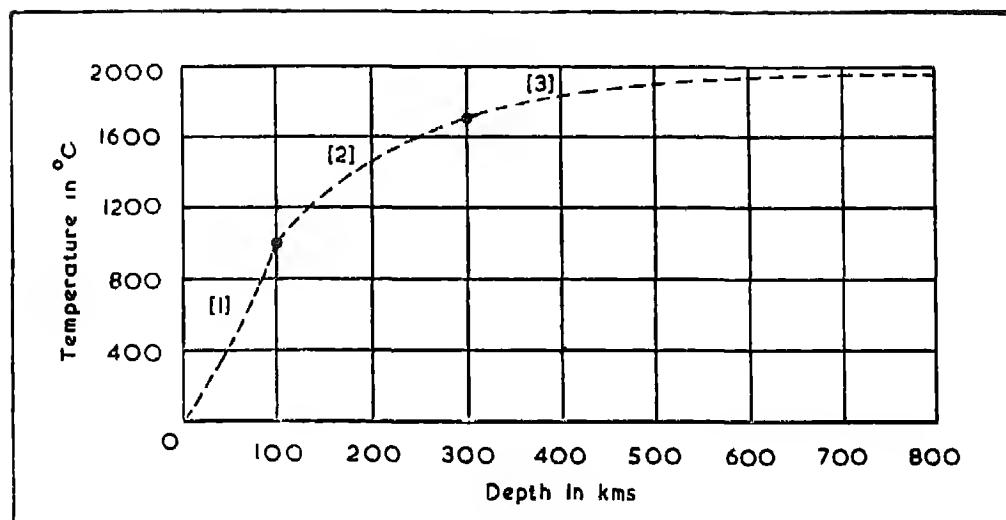


Fig. 12. Variation of temperature with depth

also produce heat in the crust.

The three basic layers, the core, the core mantle, and the crust (Fig. 11) by volume form respectively, 83 percent, 16 percent and about 0.5 percent of the earth's body.

The crust is the hard external covering

of the earth. Its average thickness is 50 kms. but it is thicker below the continents than below the oceans (Fig. 13). Its lower limit is sharply formed by the *Mohorovicic Discontinuity*. The crust has an extremely complex internal structure comprising of several layers as well as a large variety of

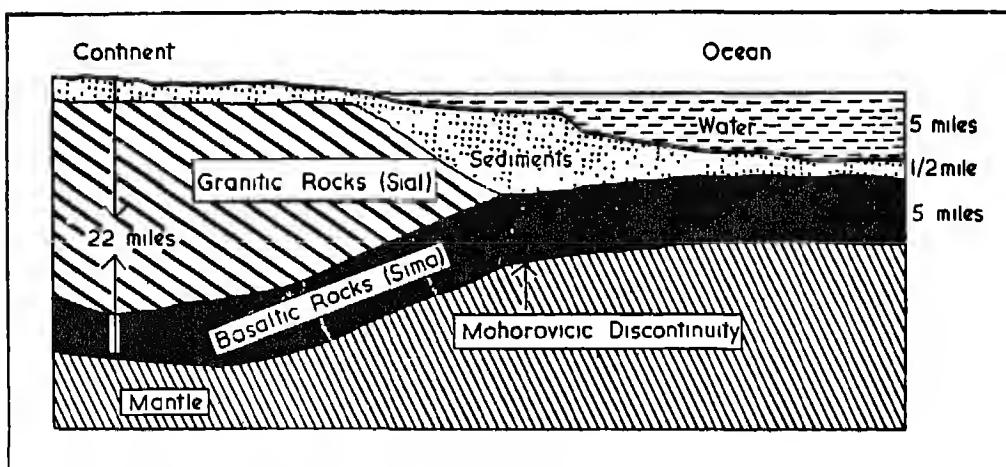


Fig. 13. Profile of the earth's crust

sedimentary, igneous, and metamorphic rocks. There are two types of crusts,— the continental and the oceanic. The continental crust is located below the continents, on the shallow seas; the continental slope, and upto abyssal depths of about 200 km. Its thickness varies

from 20 to 70 km. It is thicker below the mountains than it is below the plains. The continental crust is composed of the upper granitic and the lower basaltic layers. The oceanic crust lacks a granitic layer but is characterised by volcanic rocks and has a thickness of 5 to 15 kms.

### E X E R C I S E S

1. Explain briefly the structure of the earth ?
2. What is the significance of the variations in temperature in the earth's interior ?
3. On what basis are the layers distinguished ?
4. Name the three fundamental layers in the earth's body.
5. Why are all the sources of data on the layered structure indirect ?
6. Name the most important indirect source of data.
7. What are the three types of earthquake waves ?
8. How do we infer a change in the physical properties of the earth's interior from the velocity of the wave propagation ?
9. How do we know that the core is liquid ?
10. Give a full interpretation of the time-depth and time-distance curves.
11. Name the two first-order discontinuities.
12. Write the densities of the earth, core, mantle, and crust. Why does the core have the highest density ?
13. Attempt a detailed description of the crust of the earth.

### Books For Further Study

- Ordway, R.J. *Earth Science* New Delhi ; East West Press, 1971.  
 Lounsbury, J.F. *Earth Science* New York . Harper and Row, 1969.  
 Meinesz, V. *The Earth's Crust and Mantle*, New York : Elsevier, 1964.  
 Leet, D.J. *Physical Geology*, New York : Prentice-Hall, 1965.



## CHAPTER 4

# Materials of the Earth's Crust : Rocks and Minerals

**R**ocks and minerals mainly constitute the upper parts of the earth's crust. This outer shell on an average is about 7 km. deep beneath the oceans and about 40 km. deep below the continents.

The information about the materials of the earth's crust is derived from the direct study of rock masses which (i) occur at the earth's surface, (ii) are extracted from deep mines, and (iii) are recovered from beneath the ocean floors by drilling through them.

### Minerals :

Since rocks are aggregates of minerals it is necessary to know about the latter first. A mineral is generally an inorganic element or compound which occurs naturally. It has a definite chemical composition

and a characteristic atomic structure. A mineral has also a definite set of physical properties that are fixed within certain limits.

Approximately 200 mineral species are known. Of these about 24 minerals are major constituents of the rocks of the earth's crust. These are termed rock-forming minerals. All the minerals belong to one or the other chemical group. There are ten chemical groups : oxides, sulphides, sulphates, carbonates, halides, silicates, pyroxene, amphibole, micas, and feldspars. Examples of common minerals belonging to each of these groups respectively are hematite, pyrite, gypsum, dolomite, fluorite, quartz, augite, hornblende, muscovite, and plagioclase. All

these minerals and the chemical groups to which they belong are chemical compounds having fixed chemical composition. For example, hematite is iron oxide ( $\text{Fe}_2\text{O}_3$ ) and augite is pyroxene  $\{\text{Ca}(\text{MgFeAl})(\text{AlSi})_2\text{O}_8\}$ . The minerals have both very simple and extremely complex compositions.

The most important and the most preponderant rock-forming minerals are the silicates. Of the silicate minerals quartz ( $\text{SiO}_2$ ) is the commonest of all rocks types. So significant is the group of silicates, in terms of occurrence and proportions, that it is sub-divided into the groups of pyroxene, amphibole, micas, and feldspars.

#### Rocks :

A rock is a naturally occurring mass of solid inorganic or organic material. It forms a significant part of the earth's crust. Every rock is an aggregate of minerals, usually two or more. But a few rock varieties consist almost entirely of one mineral. A rock can be as hard as granite or as soft as mud.

For the geologists rocks are the main objects of study. They map the distribution of rocks and then draw general conclusions regarding the geological history of areas. For the geographer the study of rocks is significant in the study of topographical features and as an element of the natural environment which man encounters.

#### Major types of rocks :

Three major types of rocks have been recognised - igneous, sedimentary, and metamorphic. Each major type is further subdivided on the basis of some distinguishing characteristics, such as origin, mineral content, and texture.

Origin refers to the locales and processes of origin. Mineral content indicates the variety of minerals present in a rock type. The term texture applies both to grain size and to the arrangements of crystals of various sizes.

#### Igneous rocks .

Igneous rocks are the most abundant constituents of the earth's crust. Two origins have been proposed for the formation of igneous rocks (i) solidification of magma and (ii) granitisation. Most of the types of igneous rocks have originated through the former process.

Magma is a complex, very hot solution of silicates containing water and several gases. It originates in the deep interiors of the earth's body in the upper mantle. Magma moves upward by melting away the overlying rocks and by forcing them aside. This process is termed intrusion. Intrusion cools the magma. Magma that reaches the earth's surface and then solidifies is called lava.

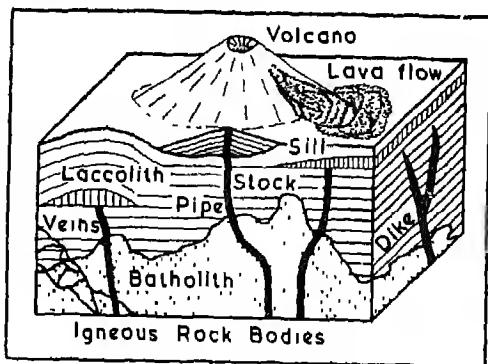


Fig. 14. Profile of a Volcano

The physical appearance of igneous rock is essentially determined by the rate of cooling of magma. The slow cooling of magma which lies deep in the crust produces large mineral crystals, and thus,

results in the formation of a coarse-grained or phaneritic texture. Huge masses of coarse-grained igneous rocks formed by the solidifying of magma at a depth below the crust are termed *plutonic rocks*. Granite is a typical coarse-grained plutonic rock.

Rapid cooling of molten igneous material or magma, either near or on the surface, produces very small crystals which are visible mainly under a microscope. These rocks have a fine-grained or aphanitic texture. On the surface, cooling can be so rapid that the various atoms cannot arrange themselves into the different structural arrangements of the silicates. Hence, no crystals are formed and the rock is said to have a glassy texture. Andesite and basalt are examples of aphanitic texture.

Some igneous rocks have been produced through two stages of cooling, slow cooling followed by rapid cooling. The large crystals formed by slow cooling are found embedded in a matrix of very small crystals formed by rapid cooling. The former are termed *phenocrysts*. The crystalline aggregate in which the former are embedded is termed *porphyry*.

In general, the silicate minerals forming the most abundant constituents of igneous rocks are precipitated in a definite sequence. The ferromagnesian minerals or iron and magnesium silicates are the first to be crystallised. These are followed by hornblende, biotite, feldspars, and quartz.

All igneous rocks are a function of the original mineral constituents of the parent magma and the rate of cooling resulting in variations in texture.

Rocks having a high proportion of ferromagnesian minerals are classified as *mafic*. They are dark-coloured and have

a specific gravity of about 3.0. Rocks which have a high proportion of quartz and the feldspars are classified as *felsic*. They have a light colour and, a specific gravity of 2.7. Both mafic and felsic rocks are produced from the same molten magma by the process of differentiation. The ferromagnesian silicates are the first to solidify. They are heavier than the stillmolten magma and hence, sink to the bottom of the magma chamber. A residual magmatic solution of a different composition is left behind. On solidifying this produces the felsic rocks.

Granitisation is the second process producing the igneous rocks of granitic variety. The minerals found in granitic rocks also occur in sedimentary rocks. These minerals, through sufficient heating are transformed into granite. This process is termed granitisation. In this process the need for having a molten phase is eliminated.

On the basis of the locale of origin the igneous rocks can be classified into *intrusive* and *extrusive* varieties. The intrusives crystallise beneath the surface and have a coarse texture. In contrast, the extrusive rocks crystallise on the surface and have a finer texture. Many of the intrusive rocks have their extrusive equivalents. Rhyolite, and basalt are the extrusive equivalents, respectively of granite and gabbro.

Figs. 14 and 15 show some intrusive rock masses. The *batholith* is the largest of them. It has an elliptical plan. The *laccolith* forces the overlying rock into an arch or dome. A *sill* is an intrusion of cooled magma lying between two pre-existing rock layers and hence is concordant. In contrast, a *dike* is discordant and cuts across the trends of the rocks which it intrudes.

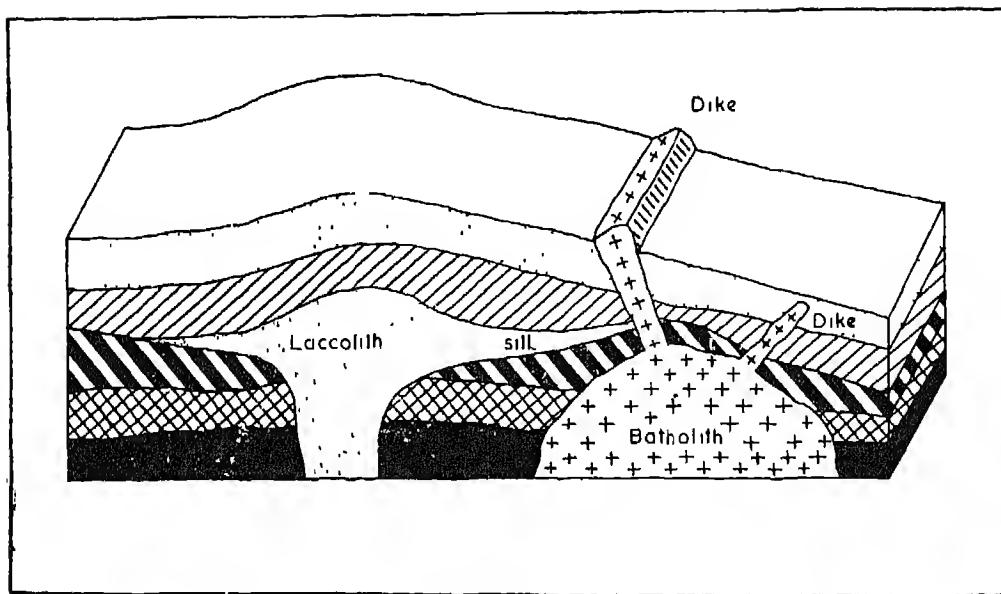


Fig. 15. Four types of Intrusive Rock Masses

The commonest extrusive rock is the lava flow. The lava flows accumulate to form thicknesses of several thousands of metres. Pyroclastics form the second group of extrusive rocks. They have erupted from volcanoes and are of various sizes. They are termed bomb, cinder, and ash in the order of their decreasing size.

**Examples and properties:** As Fig. 16 shows the igneous rocks can be classified

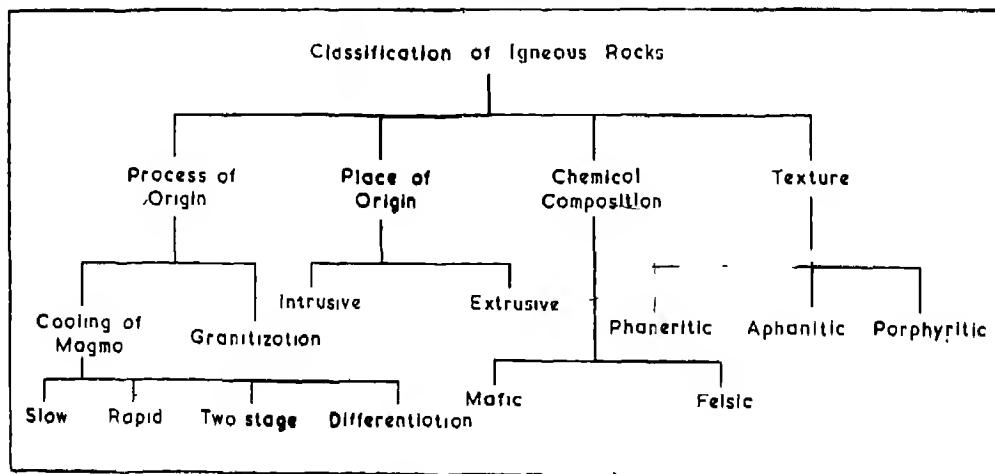


Fig. 16. Classification of Igneous Rocks

broadly on four bases : (i) process of origin, (ii) place of origin, (iii) mineral composition, and (iv) texture.

Process of origin can be either the nature of cooling or granitisation. The nature of cooling can be either slow, rapid, two-stage, or differentiation. Examples of these respectively are granite, andesite, rhyolite porphyry and biotite-periodotite. Granitisation is exemplified by granite.

On the basis of the place of origin an igneous rock can be either intrusive or extrusive. Examples are granite and obsidian respectively.

Mafic and felsic types are exemplified by periodotite and granite respectively. Rocks containing a large proportion of silica, such as quartzite and granite are also classified as *acidic*. In contrast, a smaller proportion of silica places the rocks into *basic* type, such as, gabbro and basalt. The rocks having no silicates are termed *ultrabasic*.

Phaneritic, aphanitic, and porphyritic types have their examples in granite, andesite, and rhyolite porphyry, respectively.

Any igneous rock can be fully described in terms of the bases which have been used for classifying it. Thus, granite is formed by the slow cooling of magma. It is an intrusive rock and is felsic in composition and also acidic. It has a phaneritic texture.

Some of the important igneous rocks are granite, rhyolite, pegmatite, syenite, diorite, andesite gabbro, basalt, dolerite, and periodotite.

Granite, rhyolite and pegmatite belong to the acidic group. Quartz, biotite, and feldspar are the essential minerals in all of them. Granite has a phaneritic, rhyolite a porphyritic, and pegmatite an

aphanitic texture.

Syenite has a coarsely crystalline texture and the mineral composition of feldspar, mica, amphibole, and pyroxine. It is intermediate between acidic and basic.

Diorite and andesite are also intermediate between acidic and basic. Andesite is the extrusive equivalent of diorite. Diorite has a coarsely crystalline and andesite a porphyritic texture. Plagioclase, hornblende, biotite and pyroxene are common to both. Thus both are mafic.

Gabbro, basalt, and dolerite are common basic rocks. Basalt is the extrusive equivalent of gabbro while dolerite is a hypabyssal variety. The textures of these rocks are respectively, phaneritic, aphanitic, and medium-grained. Plagioclase feldspar and augite are the common minerals.

Periodotite, an ultrabasic rock, consists chiefly of olivine and also pyroxene, hornblende, and biotite. It has a phaneritic texture and is mafic in composition.

#### *Sedimentary Rocks*

Sedimentary rocks are those which are constituted of sediments. Sediment is material from the air and water that settles down. Sedimentary rocks have been formed from sediments which accumulate at the bottom of a lake, in a river bed, or a desert plain and the bottom of the sea. Sedimentary particles vary in size from microscopic to very large fragments.

The sediments can be divided into two major groups : *clastic* and *non-clastic*. Clastic sediments are particles broken from a parent rock. Non-clastic sediments are newly created mineral matter precipitated from chemical solution or from organic activity. The clastic group is

sub-divided into *pyroclastic* and *detrital* classes. Pyroclastic sediments are thrown out from the volcanoes in the form of bomb, cinder, ash, and volcanic dust. The detrital sediments are derived from fragments or individual minerals of igneous, sedimentary, and metamorphic rocks.

The non-clastic group is sub-divided into chemical and organic sediments. The chemical sediments are precipitated from fresh or salt water and are also termed *hydrogenic* and *morganic*. Organic sediments are *biogenic* or *bipolithic* and refer to those which have been derived from the remains of living organisms.

On the basis of size the sediments can be classified into three groups (i) *arenaceous*, (ii) *argillaceous* and (iii) *rudaceous*. The arenaceous sediments are of medium size and are generally sands. Argillaceous sediments are the finest-grained mud, clay, silt, and loess. The rudaceous variety are coarse grains, such as, gravel and scree. These three size terms are also used for describing the texture of the rocks.

**Formation of Sedimentary rocks :** Sedimentary rocks are formed by compaction and cementation of layers of sediments. These two processes constitute the process termed *lithification*. Through lithification rock-forming materials are changed from the loose or soft state into a hard or indurated rock. Compaction is achieved by the pressure of layers overlying each other while cementation is effected when individual particles are bonded together by some mineral material, such as calcium carbonate (calcite) or iron oxide (limonite).

**Properties of sedimentary rocks :** Almost all sedimentary rocks possess a

layered arrangement. Together the layers are called strata, each layer is termed a bed or a stratum. The layers have different textual composition and are alternated or inter-layered. The planes of separation between beds are termed

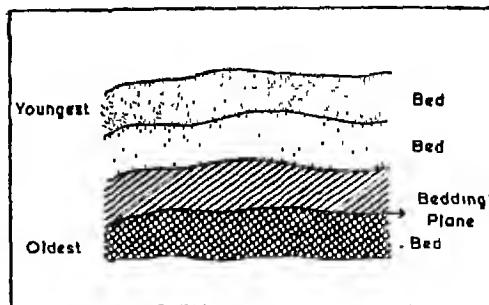


Fig. 17. Sedimentary rock

bedding planes (Fig. 17). Most sedimentary rocks are deposited in a nearly horizontal position. After lithification, the earth movements may change the original horizontal position. Some layers are uplifted, some folded, and some faulted.

Five factors control the properties of sedimentary rocks : (i) kind of rock in the source area, (provenance), (ii) environment of the source area, (iii) earth movements (a) in the source area and (b) in the depositional area (tectonism), (iv) environment of the depositional area, and (v) post-depositional change of the sediment (lithification).

The type of rocks from which a rock-forming aggregate of sediments has been derived can be known from the mineral assemblages of the resultant rock. Its properties are influenced by the nature of the rock in the source area.

The environment of the source area includes climate, topography, vegetation cover, animal population, and the

geological processes. The complex interplay of these factors as well as weathering and transportation profoundly influence the kind of sediment produced, the manner in which the sediment is transported to the place of deposition, its distribution, and its special characteristics.

Earth movements occur during or between the periods of sedimentation in the depositional area and the source area. There are three types of depositional areas,—geosynclines, shelves and intra-shelf basins. In the source area uplift takes place by orogeny and epiorogeny.

Three sedimentary environments have been recognised continental, marine, and transitional.

The post-depositional changes are effected by compaction, cementation, and recrystallization, all adding upto lithification.

**Types and examples :** Sedimentary rocks are classified on the same bases that are used for classifying sediments. The four types are pyroclastic, detrital, chemical, and organic rocks. On the basis of texture, these can be recognised as arenaceous, argillaceous, and rudaceous rocks.

A pyroclastic rock has a rudaceous texture composed of angular particles. Volcanic breccia and tuff are good examples. Large fragments are often embedded in a matrix of finer debris. They are composed of silicate minerals of magmatic origin.

In order of the decreasing size of their constituent particles, detrital rocks include conglomerate, sandstone, and shale. Conglomerates contain pebbles and cobbles which are generally rounded and produced by rolling on a stream bed or by waves along a sea coast. Conglomerates have a

rudaceous texture. The mineral contents are highly variable since the particles have been derived from all kinds of rocks.

Sandstone is an arenaceous rock and has a coarse texture. Quartz is the main rock-forming mineral. The rock consists of cemented sand grains.

Shale is the most abundant of all sedimentary rocks. It is compacted silt and clay. *Lamination*, paper thin layers, is the chief diagnostic property of the rock. *Kaslin* and clay minerals are abundant in it. It has a fine argillaceous texture.

True hydrogenic limestone consists predominantly of mineral calcite which is calcium carbonate. Limestone may have porous, colitic (spherical particles) or massive texture and is calcareous in composition. Some varieties are crystalline in appearance. Chalk is a common variety of limestone.

Dolomite is a variety of limestone containing more than 50 per cent of mineral dolomite which is a combination of calcium and magnesium carbonates.

Rock gypsum is white to reddish in colour. It may occur in massive or fibrous form. Along with rock salt it forms the group of *evaporites*. Gypsum and rock salt are formed by the evaporation of sea water and salt water lakes. The compositions of gypsum and rock salt are calcium sulphate and sodium chloride, respectively. Rock salt occurs in salt domes and saline deposits and displays a crystalline or granular form.

Organic or biogenic rocks include organic limestone, chalk, peat, and coal.

Organic limestone is derived from either plant or animal fragments or through the secretion of calcium carbonate by coral reef builders which inhabit the warm,

shallow seas.

Chalk is a calcareous rock made up of microscopic skeletal elements from a variety of limesecreting organisms. It is soft and white, and is composed of almost pure calcium carbonate.

Coal and peat represent the accumulation of vegetation which originated in swamps. Peat is the first stage in the transformation of vegetable matter into coal. It contains about 57 percent carbon. Peat is transformed to coal by increase in pressure which expels the moisture and gaseous constituents and increases the proportion of fixed carbon. Peat, lignite, bituminous, and anthracite are grades of coal which contain, respectively, higher proportions of fixed carbon.

#### *Metamorphic rocks and their formation*

Metamorphic rocks are formed by physical, chemical and mineral alteration of other rocks under the conditions of high pressure, intense heat, or shearing stress, or by a combination of these (Fig. 18). The process of change is termed metamorphism. It operates at great depths of thousands of metres beneath the surface. The formation of metamorphic rocks takes place, always, in the solid state.

Four metamorphic processes have been identified : (i) mechanical deformation, (ii) re-crystallization, (iii) chemical recombination, and (iv) chemical replacement.

At great depths the pressure is very great. The rocks are crushed and their texture is changed. Under such conditions, for example, shale develops slaty cleavage.

Through re-crystallization the minerals present in a rock before metamorphism are changed into larger crystals during metamorphism. For example, during the

metamorphism of limestone into marble, larger calcite crystals are formed.

Chemical recombination refers to the process in which a rock containing more than one mineral species is metamorphosed into a new rock by a recombination of the minerals of the original rock.

At great depths liquids and gases penetrate small fractures and inter-grain spaces. Some original materials are dissolved and replaced by others. New minerals are thus formed. This process is termed replacement.

Two general types of metamorphism are recognized : *Contact metamorphism* and *regional metamorphism*.

Contact metamorphism also termed local metamorphism is the process of change effected by heat in the proximity of magmatic intrusion in the affected rock. The invaded or host rock is changed by both the heat of the magma and the chemical constituents released by it. The effects of this type of thermal metamorphism decrease with increasing distance from the contact zone. Contact metamorphism produces chemical replacement, re-crystallization, and mechanical changes in the host rock. The host rock receives large amounts of metallic substances from the magma and becomes a source of valuable minerals.

Regional metamorphism is the process in which rocks are altered mainly through increase in pressure but partly also in temperature. It is also termed tectonic or dynamic metamorphism. The increase in mechanical stress or pressure is caused regionally by the deformation of crustal rocks. Regional metamorphism is associated with mountain chains. Slaty cleavage and plastic deformation are the two

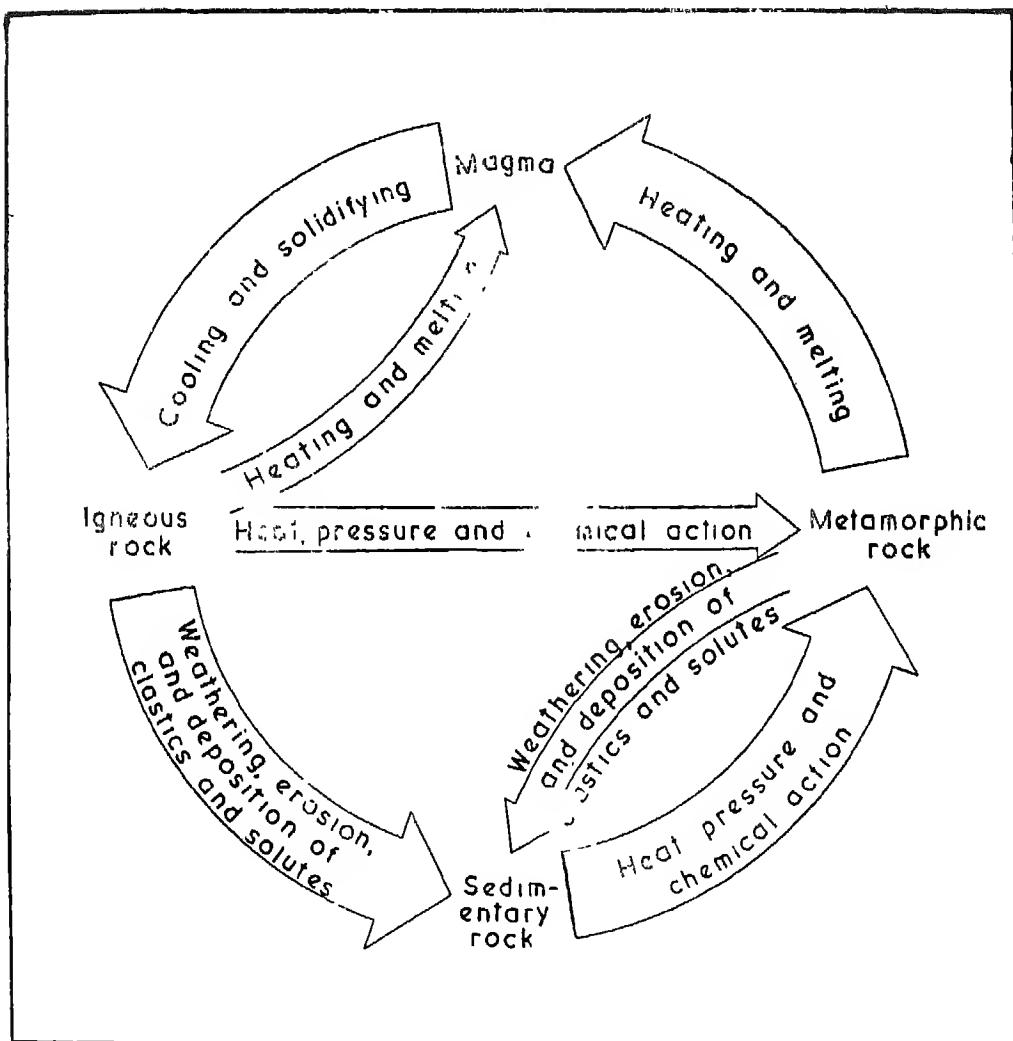


Fig. 18. Rock Cycle

important results. Re-crystallization is also an effect of the same process.

**Types, properties and examples** · Two broad classes of metamorphic rocks have been recognized, (i) *foliated*, and (ii) *non-foliated*.

Foliated rocks are characterised by parallel

arrangement of slaty minerals, such as, the micas. Foliation is produced during regional metamorphism. The degree of foliation is related to the intensity of metamorphism. The foliations are ultimately changed into bands. The series of shale, slate, schist, and gneiss represent increasing

grades of metamorphism.

In the non-foliated metamorphic rocks the mineral grains are equi-dimensional, hence there is no specific orientation. Quartzite and marble are good examples.

Slate, schist, gneiss, phyllite, quartzite, amphibole, serpentine, and marble are some of the common metamorphic rocks.

Slate, schist and gneiss have all been derived ultimately from the sedimentary rock shale. As the intensity of metamorphism increases shale is converted into slate, slate into schist, and schist into gneiss. Slate has an aphanitic texture and a marked cleavage along which it can be split into thin cohesive plates. Slaty cleavage is formed during compression in the phase of regional metamorphism. The flaky minerals were rotated so that they were arranged parallel to each other and perpendicular to the direction of compression. Thus the cleavages were produced.

Schist has pale colours and a foliated texture. The foliation surfaces are plain, wavy, or contorted. The rock can be easily cleaved and it is very soft. The rock-forming minerals are quartz, muscovite, and biotite. The micaceous flakes and folia are clearly visible to the unaided eye.

Gneiss is coarser grained than schist. It usually consists of alternating bands of light and dark-coloured minerals. Mica-

ceous layers are a characteristic. The rock-forming minerals are quartz, orthoclase, plagioclase, biotite, muscovite, and pyroxene.

Phyllite is dark gray or greenish in colour. There is a glossy sheen on the surface of splitting. The foliation is often wavy. The rock is easily cleaved but the thin plates are not usually as tough as slate. The rock-forming minerals are sericite, chlorite, and quartz.

Quartzite is the metamorphosed form of the sedimentary rock sandstone. It is a compact siliceous rock and consists of detrital quartz grains in which the pores are filled with quartz cement. The metamorphism involved is due to both heat and pressure.

Amphibole has a green to dark green colour. The rock-forming minerals are hornblende and actinolite. It is occasionally hard and massive. It has a foliated texture with interlacing fibres.

Serpentine is generally of a green colour. It is massive and gives a soapy feel and has a fibrous or foliated texture. The main rock-forming mineral is an alterative product of olivine.

Marble is the metamorphic form of limestone and has various colours, white, yellow, green, black and red. Calcite and dolomite are its main rock-forming minerals. It has a massive, granular or fibrous texture.

## EXERCISES

1. Define a rock.
2. Name the three main classes of rocks.
3. Describe with the help of a sketch the relationship between the three types of rocks.

4. How are sedimentary rocks formed ?
5. Name some of the common sedimentary rocks and their metamorphic equivalents.
6. Define a mineral.
7. Name some of the common minerals and their associated rock types.
8. What are the two processes of metamorphism ?
9. How would you distinguish an acidic from a basic rock ?
10. Name the five factors which control the properties of the sedimentary rocks.

#### Books for further study

Borner, R. *Minerals, Rocks, and Gemstones*, Edinburgh · Oliver and Boyd 1967.

Tyrell, G.W. *The Principles of Petrology*, London · Methuen and Co. 1958.

Read, H.H. *Elements of Mineralogy*, London : Thomas Murley & Co. 1957.



## CHAPTER 5

# Rocks and Associated Economic Minerals

We have learnt from the previous chapter that all the rocks are made up of a large number of minerals. Thus, all the minerals are associated with one or the other kind of the three main types of rocks, igneous, sedimentary, and metamorphic. Although the number of minerals is very large only a few are of economic importance. The potential use of a large number of minerals have not been discovered as yet.

### Economic minerals associated with sedimentary rocks

The number of economic minerals associated with sedimentary rocks is less than that associated with igneous rocks. Their industrial importance is also less. Some of the common minerals in this group are

rock-salt, gypsum, nitre, pyrite, and hematite.

**Rock-salt** is common salt. It occurs in the form of cubical crystals and granules. When pure, it is perfectly white or colourless but it may be yellow, brown, or red as well. Rock-salt is transparent or translucent. It is easily soluble in water. Rock-salt deposits occur as extensive geological beds and have been produced by the evaporation of enclosed or partly enclosed bodies of sea-water.

**Gypsum** is hydrated calcium sulphate. Crystalline and prismatic forms are quite common. It also occurs in laminated, granular, and in compact and fibrous masses. Generally gypsum produces thin plates as cleavages. Its crystals are colour-

less. Cleavage planes have a shining lustre. It can be opaque, translucent, or transparent and can be easily scratched with a finger-nail. The chief producers are the U.S.A., France, Spain, Great Britain, Canada, Italy, and Germany. It is used in the manufacturing of cement, fertiliser, paper, crayons, paints, rubber, plaster of paris, and construction materials.

**Nitre** or saltpetre is nitrate of potash. It occurs in large quantities in the soils of certain countries, such as India, Algeria, Egypt, Persia, and Spain. Chile is an important producer of saltpetre. It is used in the metallurgical and chemical processes and in the manufacture of explosives, and fertilisers.

**Pyrite** is iron sulphide. Pyrite is a common constituent of many ore veins. The chief producers are Spain, Norway, Portugal, Cyprus, Germany, Italy, Japan, France, and the U.S.A. From pyrite is recovered sulphur and a large number of minerals, nickel, iron, and silver.

**Hematite** occurs in both sedimentary and metamorphic rocks. (It is a sesquioxide of iron ( $\text{Fe}_2\text{O}_3$ ) and a major ore of iron). It gives its red colour to rocks and soils. It contains about 70 per cent iron. It is used as a gemstone in the making of rings, cuff links, and tie-pins. In its natural occurrence hematite is found alternating with chert and magnetite in thin layers. It can occur as veins or layers in limestone.

#### Minerals associated with Igneous Rocks

A large number of minerals having a wide variety of uses are associated with igneous rocks. Some, such as iron, nickel, copper, lead, zinc, and manganese, are used in the metallurgical industries and others, such as diamond, gold, and platinum are the measures of wealth. Gold is used in the

making of coins and jewellery.

**Platinum** belongs to a group of rare minerals that is essential to modern industry. It occurs in nature both as a native metal and alloy. It occurs in many types of rocks in many ways from which placer or alluvial deposits are formed and these supply the major output. Platinum is separated from associated metals by a complicated series of operations. It is produced mainly in the U.S.S.R., Canada, South Africa, the U.S.A., Colombia, and Ethiopia. The mineral is used in the making of catalysts, and in dentistry and jewellery.

**Diamond** and graphite are the two naturally occurring forms of carbon. In diamond the carbon atoms are closely packed and strongly bound to each other. That is why it is so hard. Most of the world's supply of diamond comes from a dense basic rock known as Kimberlite. These rocks occur as pipes injected from great depths into the overlying layers. The well known diamond pipes occur in South Africa, in Ural Mountains and in the Rayalaseema region of India. Diamond is the primary mineral in the ultrabasic rocks but it also occurs in alluvial deposits. Diamond is pure crystalline carbon and also occurs as crystal. This form is attained as a result of tremendous pressure and heat. The brilliant-cut diamond disperses white light and produces brilliant flashes of colour known as 'fire'. Diamond occurs in bluish-white, white, yellow, brown, red green, blue, and black colours. Diamond is used as a gemstone and as an abrasive in rock drills and diamond saws.

**Iron** is next only to aluminium in being the most widely distributed and abundant mineral. It constitutes about 4.5 per

cent of the earth's crust. It is found in its native form in eruptive rocks, mostly associated with nickel and cobalt and is included in a large number of rock-forming silicates. Magnetite, hematite, limonite, siderite, chalybite, pyrite, and glauconite are the principal iron-bearing compounds. In the Lake Superior region there are vast reserves of iron ore. Iron ore is also derived from laterite which is a product of weathering. The U.S.A., the U.S.S.R., Canada, Brazil, France, India and Australia are the main producers of iron. Iron rich laterites are mined in Cuba and the Philippines. The chief use of iron is in the manufacture of steel.

**Gold** is a precious, non-ferrous metal. It is used as a measure of wealth and occurs widely diffused in nature in its native form. Generally, it is found in lodes associated with quartz. Gold mines have also been developed in placer deposits. When pure, gold is the most ductile and malleable of all metals. It is recovered from two types of ores : (i) free milling ores from which gold is recovered by crushing and amalgamation, and (ii) refractory ores which yield their gold by smelting. Gold is produced in Transvaal (South Africa), the Soviet Union, the U.S.A., Canada and Australia.

**Silver** is a non-ferrous mineral and metal. It occurs in nature in a free state as well as combined with copper, gold and other metals. Next to gold, it is the most malleable and ductile of all metals. The chief producers of silver are Mexico, the U.S.A., Canada, Europe, and Bolivia. Silver is used in coinage, jewellery, electro-plating, medicines, photography, and coloured glasses.

**Nickel** is quite common in the earth's

crust. It occurs in combination with sulphur and iron and never as native metal. White and malleable, it is unaffected by moist or dry air and is capable of taking a high polish. Fifty per cent of the world supply of nickel comes from Sudbury, Canada. The U.S.A. produces about 25 per cent of the total production of the world. Nickel is mainly used in the manufacturing of alloys, German silver, white metal, and nickel bronze. Nickel-Steel alloy has a greater strength and hardness than carbon-steel alloy. It is used in the manufacture of armour-plate, aircraft body, and motor cars.

**Copper** is a non-ferrous mineral. It has a strong affinity to sulphur. Copper sulphide occurs widely in major ore bodies. Copper ore which occurs as lodes and veins is mainly mined in the U.S.A., Canada, Chile, Peru, Zambia, and Zaire. Copper has a wide variety of uses in electrical appliances as it is very good conductor of electricity. It is also used as an alloy in producing brass, bronze, gunmetal and nickel silver.

**Zinc** is a bluish-white brittle metal. It is a non-ferrous metal and can be rolled into sheets or drawn into wire at temperatures between  $100^{\circ}$  and  $150^{\circ}\text{C}$ . Most of the zinc produced is obtained by an electrolytic process. The chief producers of zinc are the U.S.A., Belgium, Canada, Poland, Germany, Australia, Great Britain, France, and Norway. Metallic zinc is used for coating or galvanising iron and in the manufacture of alloys, the chief of which is brass. Zinc oxide and zinc sulphide are used as pigments. Other salts of zinc have wide industrial applications.

**Lead** does not occur pure. It is a bluish-grey metal. The freshly cut surface reveals

a bright metallic lustre. It is so soft that it can be scratched with the finger-nail and makes a black streak on paper. Lead has a high specific gravity of 11.34. In semi-molten condition it can be rolled or pressed into thin sheets. Most lead ores contain silver. The chief modes of occurrence of lead are as lodes and veins. Lead and its compounds have a large variety of uses. It is used in the making of sheets, pipes, cable covers, ammunitions, foil alloys, pigments, glass, rubber, dyeing and printing, insecticide, and medicine. Lead is produced in the U.S.A., Mexico, Australia, Canada, Spain, India and Germany.

**Manganese** generally occurs in nature in the oxides of the minerals. It is extracted in the electric furnace by smelting one of the oxides, carbonates, silicates, or sulphides of the mineral. The most important manganese deposits are the oxides of a sedimentary or residual nature occurring as beds of layers of nodules with iron compounds. All deposits of manganese oxides are formed by the disintegration of manganese-bearing minerals of igneous and metamorphic rocks. The chief producers

of the mineral are the Soviet Union, India, the Gold Coast, and Brazil. The major use of manganese is in the manufacture of alloys which have great importance in the steel industry. It is also used, as oxide, in the industries of glass, paint, varnish, dry batteries, and disinfectants.

#### **Minerals associated with Metamorphic Rocks**

Garnet and sillimanite are two of the many minerals associated with metamorphic rocks.

**Garnet** occurs in many varieties which together constitute the garnet family. All garnets are heavy and hard. Garnets are used as gemstones and abrasives. It is mined in eastern U.S.A., Czechoslovakia, India, Sri Lanka and South Africa.

**Sillimanite** occurs as long needle-shaped crystals. Shades of brown, grey, and green are its characteristic colours. It occurs in those rocks which have been metamorphosed under high temperatures and moderate stress. Sillimanite is used in high grade refractories. In India it is mined in Assam and Madhya Pradesh.

#### **E X E R C I S E S**

1. What are the properties of economic minerals associated with sedimentary rocks?
2. Describe hematite and pyrite.
3. Describe the properties of diamond.
4. Name the minerals associated with metamorphic rocks and describe their properties.

## PHYSICAL BASIS OF GEOGRAPHY

## Books for further study

Borner, R. *Minerals, Rocks, and Gemstones*, Edinburgh ; Oliver and Boyd, 1967.

Tyrrell, G.W. *The Principles of Petrology*, London ; Methuen & Co. 1958.

Read, H.H. *Elements of Mineralogy*. London : Thomas Murley & Co. 1957.

## CHAPTER 6

# Rocks and Associated Land Forms

**L**andforms are generally associated with specific rock types. Rocks can be differentiated on the basis of their resistance to weathering and erosion. These differences account for different landscapes.

Rock resistance to weathering and erosion is determined very largely by four properties of rocks : hardness, jointing, permeability, and porosity.

**Rock hardness** varies a great deal. It depends on the minerals constituting the rocks, the nature of their cementation and the degree of their compression. Incidentally, it is the minerals of the rocks which are classified in Mohs' 'Scale of Hardness'. This scale begins at 1 which indicates very soft and ends at 10 which means extremely hard. Gypsum and quartz have hardness values of 2 and 7 respectively. Igneous

rocks are harder than the sedimentary ones. The hard rocks are weathered and eroded slowly and to a lesser extent than the softer varieties. Quartzites and sandstones provide two good examples of hard and soft rocks. Diversity in landscape and changes in it are the results of weathering and erosion. Hence, the hard rocks do not produce the complexity of landscape which characterises the areas of softer rocks. Even though hardness of rocks is an important factor in the evolution of land forms, it is not the most important. It is a less important determinant of the resistance of rocks in weathering processes but more important in the processes of erosion. Chemical weathering of rocks is not affected by their hardness.

**Rock-jointing** is the most important determinant of the resistance of rocks to

weathering. Jointing increases the area of the rock surface which is available to attack by chemical processes, allows water to enter the rock, and provides lines of weaknesses through which the processes of mechanical weathering can operate. Joints are planes of weaknesses and appear as small cracks. In sedimentary rocks the joints are arranged at right angles to the bedding planes and in igneous rocks at right angles to the margins of the intrusion or extrusion. Joints are small, discontinuous, or long. The long joints form a master-joint pattern.

In igneous rocks the joints are rectangular. Where the sedimentary rocks have experienced various phases of stresses the joint-pattern is very complex. In crystalline rocks joints extending parallel to the surface are common.

Weathering is helped by jointing patterns in various ways. Chemical weathering is concentrated along joints and bedding planes. Limestone landscape features, such as dolines, dry valleys, sinks, and underground passages are related to master joints. Large caverns are controlled in their size, shape and growth by the pattern of joints through which the solution process operates.

In granitic areas chemical attacks along the joints produce cuboidal blocks and eventually the granite tors are rounded. Sub-surface boulders are produced in the areas of wider spacing of joints from joint-bounded rectangular blocks of granite. Joints help the action of frost and ice in mechanically disintegrating the rocks into angular blocks. Lastly, exfoliation in granite is related to sheet jointing. Joints help, directly and indirectly, the processes

of erosion as well. Streams follow the joints while eroding the surface rocks. Erosion by sea waves through the joints on the cliffs produces steep-sided inlets. Domal shape of granite landscape and straight cliffs on the ridges have been produced under the control of joints.

**Permeability of a rock** is defined as the capacity of rock to allow water to pass through it. Permeability is determined by the presence of bedding-planes and joints. It helps the mechanical disintegration of rocks as well as chemical weathering. Permeable rocks reduce the surface run-off, an important agent of weathering and erosion, by permitting it to enter its body. Hence, a permeable rock will be resistant to erosion and form an upland. Impermeable rocks, such as clay or shale, promote a large surface run-off and stream erosion and hence, are eroded into undulating valleys and lowlands. Where hard limestones and softer shales, the former highly permeable and the latter highly impermeable, occur together, the limestones feature as high plateaus, escarpments and ridges and the shales as valleys.

**Porosity of a rock** is defined as the presence of pores between the constituent mineral particles of a rock. In some rocks these pores are large and inter-connected, while in others the pores are totally absent. Pores allow water to enter the rock but may not allow it to pass through. A good example is that of chalk. Chalk is porous but impermeable. Porosity retains water, and when water freezes, it expands and exerts pressure resulting in granular disintegration and in weakening of the rock's coherence. Porosity also promotes chemical decay. By allowing a part of the surface run-off to go underground porosity

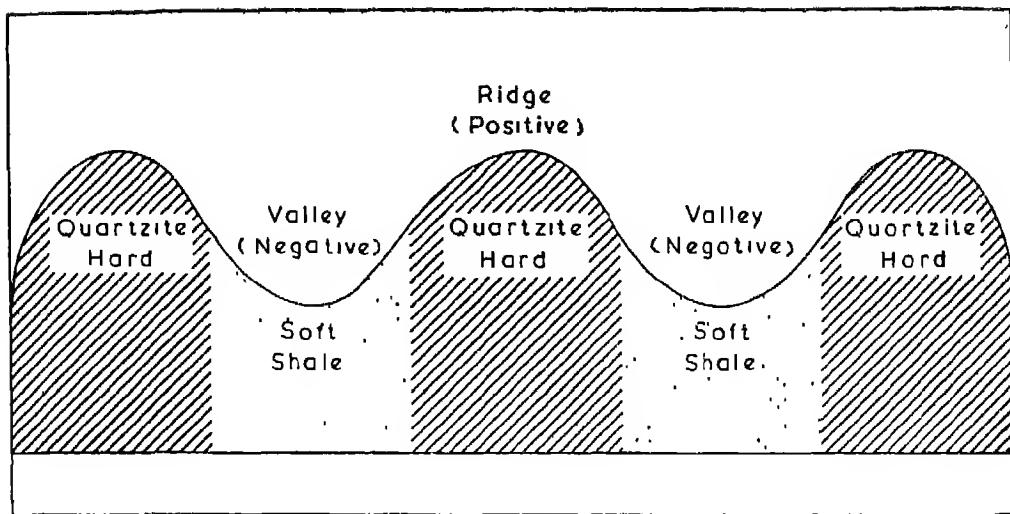


Fig. 19. Rock Hardness and Relief Features

reduces surface erosion.

### Rocks and relief features

Rocks which resist weathering and erosion form high relief features (Fig. 19). Such rocks are hard and have fewer joints, and a high permeability. Quartzites and limestones for example form bold escarpments, hills, and uplands. Rocks which are easily weathered and eroded, such as sandstones, form the valleys and other low-lying features. The processes of relief-formation always attack the rocks selectively, eroding the softer rocks to a greater extent than the harder rocks. Hence the ridges are of harder and the valleys of softer rocks.

### Rocks and characteristic landscape

Landscapes evolve as a result of the interaction between rocks and landscape-forming processes, such as the erosional and depositional activities of river, glacier, wind, sea-waves, and underground water. Thus, rocks and landscape processes become significant in the formation of land-

scapes. Now, the rocks have different properties and different types of interactions even with the same process. Hence, the resultant landscapes vary in their attributes. Also, each type of rock gives rise to its characteristic landscape. This is specially so, in the case of rocks which occur singly over extensive areas. Thus, we have granite, limestone, chalk, and clay landscapes which occur extensively and individually in some parts of the world. Where, however, a large variety of rocks, with different type of interactions with the landscape processes, occurs in combination, the characteristic landscape is missing.

**Granite landscape** essentially comprises domes and tors. Granite contains many kinds of joints, linear and spherical. Along these the rock disintegrates through the processes of mechanical and chemical weathering. Chemical weathering affects granite through its joints upto depths of more than 30 metres. The sub-soil weathering produces granitic boulders. Granite is

also affected by sheeting which is large scale exfoliation i.e., removal of cover sheet by sheet. The detailed outline of a granite landscape owes its origin to joints rather than to other factors. Exfoliation takes place in a typical spheroidal form.

The high uplands characteristic of granite areas are comprised of domes and granite bosses. These are known as batholiths. These appear as domes after the overlying rocks are removed. These domes are of enormous size. The Patagonian batholithic dome is 1100 km. long and 120 km. wide. This typical shape is produced by exfoliation. Surrounding the dome are older rocks which have been denuded to greater depths and hence, by contrast, the dome stands out prominently. Such domes are quite common in the Telengana and Rayalaseema regions of Andhra Pradesh. Along the foot of the domes are wide aprons littered with boulders. These sloping surfaces are the pediments.

Tors are residual features and are formed when more easily weathered material surrounding the resistant bedrock has been removed. Generally, tors are produced by deep sub-soil weathering or rock-rotting. A large number of pillow boulders have been produced. These are surrounded by fine-grained products of rock decay. Deep weathering follows the joint-patterns very closely. After the fine weathered material is removed, the boulders form a bizarre-looking feature in which the boulders are arranged vertically but topsy-turvy.

In addition to uplands, domes, and tors the granite landscape has its own ridge-and-valley topography and typical drainage pattern. There is differential erosion producing ridges and valleys. On the domes the typical drainage pattern is radial. In

the lowered surfaces granite dikes extend as striking linear ridges in many directions.

**Limestone landscape** develops best in the areas where limestone beds are well-jointed and gently sloping, and the climate humid. Both mechanical and chemical weathering and fluvial erosion act on the limestone beds. Surface water enters the body of limestone through innumerable openings of vertical joints. On entering the body of limestone rocks the water goes down and encounters the horizontal bedding planes and spreads laterally. The joint-planes and bedding-planes get widened by chemical action.

In a limestone topography like sink holes, dry valleys, poljes, and large valleys with sharp valley-sides, are produced by the solution action of water aided by mechanical erosion. The limestone uplands are generally bounded by bold cliffs on which can be observed limestone windows, small caves, and entrances to large caverns.

Caverns are as characteristic of the deeper interior parts of limestone uplands as the sinkholes are of their ground surfaces. Caverns can be long, domal, or tunnel-shaped. In each, however, the deposits formed of evaporation are typical. Such deposits hanging from the ceiling are known as stalactites and those rising above the floor as stalagmites. Through many caverns run the underground streams. The collapse of the caverns and mechanical erosion on the surface create a very rugged landscape. In it there are many residual, rugged-shaped, isolated hillocks and irregular depressions. The angularity of the landscape is characteristic. Such a topography is well known as a 'Karst' landscape, after the province Karst in Yugoslavia which has this characteristic

scenery.

In the areas where limestone beds occur folded the large rivers flow through gorges bounded by bold escarpments. Rock

pinnacles add to the weird topography. These erosional forms occur at the edge of the uplands and on the escarpments, and owe their origin to the surface run-off,

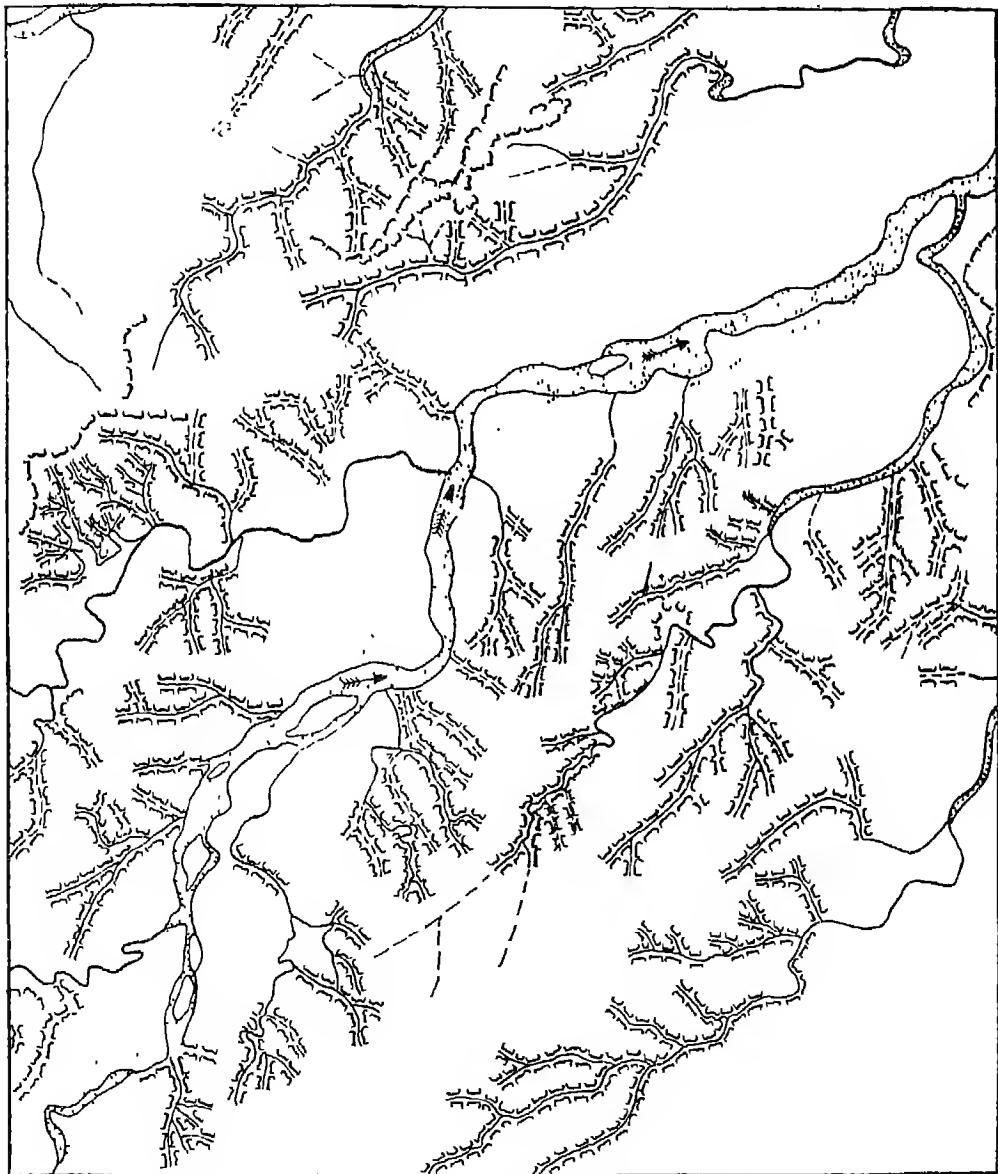


Fig. 20. Clay Topography

chemical action, and river erosion.

**Chalk landscape** : Chalk is a soft, homogeneous limestone. It has a close and evenly spaced system of minor joints and bedding planes, and is, therefore, attacked uniformly by chemical weathering. Relatively smooth landform profiles are produced.

Escarps constitute the most characteristic landscape feature. A chalk region is characterised by a large number of dry valleys. The most spectacular feature of the chalk landscape is the coastal chalk cliff. These cliffs are strikingly vertical and represent a balance between the rate of erosion and fall of loosened chalk masses from the top. Cove, bay, promontory, and stacks are associated with chalk cliffs and escarpments.

**Clay landscape** : Clay consists of very small particles with minute pore-spaces. It is compact and highly consistent and therefore, tends to retain many erosional features. Where clay alternates with easily erodable beds, the typical topography developed consists of ridges, earth-pillars

gully surfaces, bold scarp-faces, and various shapes of masses of bedrocks. This is the well-known badland topography so typical of the Chambal basin of Madhya Pradesh.

In a clay landscape, the drainage lines form a dense net work (Fig 20). While the drainage pattern is typically dendritic in flat plains, in sloping areas it develops a parallel pattern. River channels have meandering forms. Such landscapes are to be seen commonly in the Ganga basin.

Deltas and estuaries are the common landform features developed in clay regions. A Delta is a triangular feature formed by river deposition near its mouth. (1) A large number of distributaries fan out toward the coast on the deltaic surface dividing it into smaller triangular units. (2) Such is the world's largest delta the Ganga-Brahmaputra. Where large scale deposition has been prevented by tides near the river mouths, estuaries are common features. An estuary is a funnel-shaped feature located near the mouth of the river. The Narmada and Tapi mouths are such estuaries. While estuaries are small, deltas are of an enormous size.

### EXERCISES

1. What is rock hardness ? How does it affect weathering of rocks ?
2. Explain rock-jointing.
3. Distinguish between rock permeability and rock porosity.
4. What is karst topography ? Name some of its major features.
5. How does the mineralogical composition of rocks affect their chemical weathering ?
6. What are the essential attributes of a granite landscape ?

7. Attempt an analysis of the properties of chalk and the features of a chalk landscape.
8. What is a bad-land topography ?
9. Why do the drainage lines form a dense network in clay area ?

#### Books for Further Study

- Pitty, A.F. *Introduction to Geomorphology*, London, Methuen & Co. 1971.
- Small, R.J. *The Study of Landforms*, Cambridge, Cambridge University Press, 1972.
- Thornbury, W.D. *Principles of Geomorphology*, New York, John Wiley, 1969.



## CHAPTER 7

# Soils

All over the world, mankind has lived and continues to live off the soil. An enormous variety of products derived from the tilling of the soil has sustained human groups even from the Neolithic times. The march of civilisation has been characterised by the expanding frontiers on terrain and more intensive use of soil. Man's occupancy of land has been very largely controlled by spatial variation in the intrinsic properties of the soil, which in their own turn have determined the extent to which they can be cultivated. In the agricultural orient the distribution and density of population have conformed to the persisting patterns of soil fertility and

productivity. Regionally, good soils have attracted man to settle down while bad and impoverished soils have caused his exodus.

### Definition of soil

The science which studies soils is known as pedology. The pedologist defines soil as the surface material which has distinctive layers or horizons (Fig. 21). It has distinctive physical, chemical and biological characteristics. Soils support one or the other kind of vegetation. Soil comprises mineral and organic particles, while the sub-soil or bed rock is composed wholly of minerals.

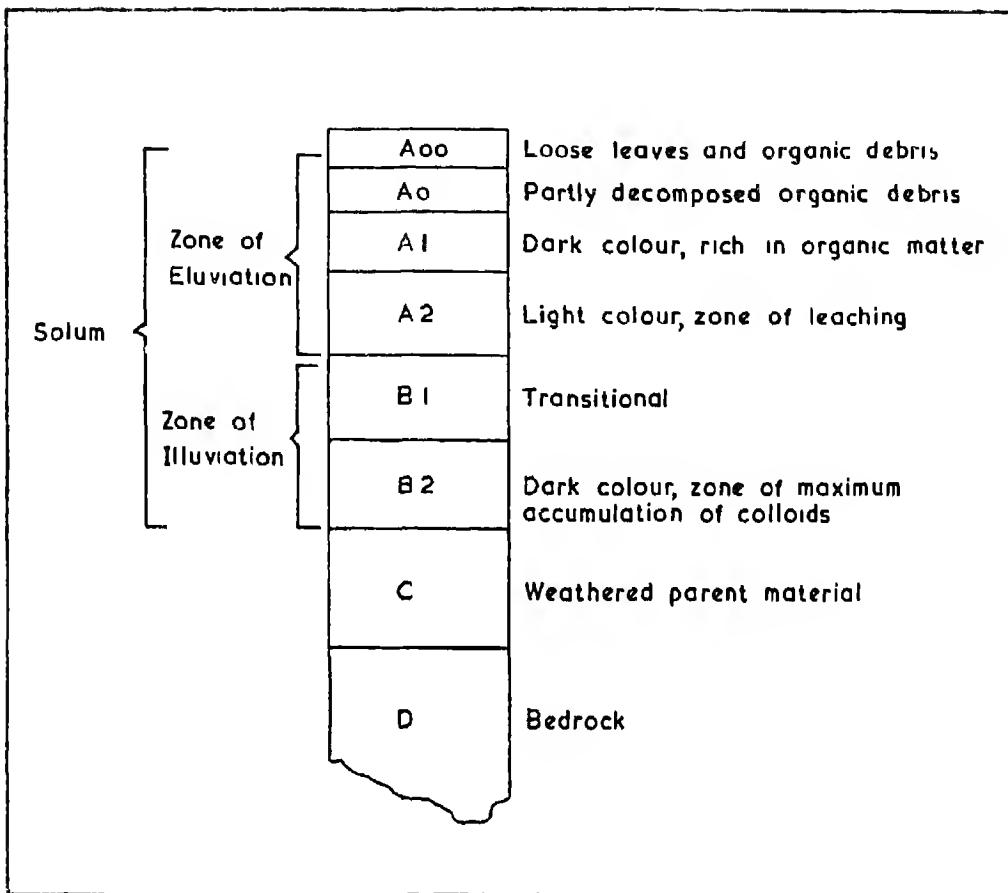


Fig. 21. Generalised Soil Profile

#### Factors in soil formation

Soil is a resource that develops over a long period, very slowly, through the mechanical and chemical weathering of the bedrock and incorporation of organic remains. These processes produce horizons in the soil, each horizon having distinctive physical, chemical, and biological characteristics.

According to the Russian pedologist Dokuchayev (1846-1903), there are five soil-forming factors : local climate, parent

material, plant and animal organism, relief and elevation and the age of the soil itself. Further, constructive and destructive activities of man related to soil erosion and soil conservation, also directly and indirectly affect soil formation. The two most important factors of soil formation on a regional scale, are the parent material and the climate.

#### Parent Material

It is the parent material which undergoes mechanical and chemical weathering. The

weathered product incorporates biological remains and is changed into true soil (Fig. 21). Parent material or the bed rock is comprised entirely of minerals. The minerals constitute the inorganic factor in soil formation.

The mineral contents of parent rocks from which the soil is derived affects the rate of their mechanical and chemical weathering and their mineral composition. The latter is reflected in the physical and chemical composition of the soils. Different parent rocks weather at different rates. Rocks having varied and more complex mineral composition weather more easily. For example, rocks with quartz are far more resistant than calcite, while gypsum is one of the softest of minerals. Calcareous rocks on weathering produce shallow soils.

The parent materials of soils are derived from all the three main classes of rocks—sedimentary, igneous and metamorphic. However, more frequently they are derived from sedimentary rocks. Glacial moraines, loess, and alluvium are the more common parent material. Among these the flood plain alluvium and river-bed alluvium weather into the alluvial soils which cover large parts of the earth.

Colour, texture, structure and rate of weathering and the presence of plant nutrients, such as calcium, phosphorus, nitrogen, potassium, and sodium in all soils, are determined by the properties of the parent materials. But parent material is one of the three passive factors, the other two being, topography and time. The active factors are climate and biological action.

#### *Climate*

In general, soil formation is an interplay

of the passive factor of parent material and the active factor of climate. Acting over a long period climate tends to reduce the differences caused by parent material. Where its role has been short-lived, the parent material itself gets reflected in the soil properties. Thus two different parent materials may produce the same soil in one climatic context, and the same parent material may produce two types of soil in two climatic regions. The sandy and organically poor desert soils of the Thar have been evolved from both sandstone and granite rocks under conditions of a desert climate. On the other hand, the crystalline granite rocks produce lateritic soil in the moist climatic areas of the Rajmahal Hills, and the dry Chilka soil in the drier regions of Andhra Pradesh. On the whole, climate is the most important soil-forming factor operating directly through weathering and indirectly through biological activity. It operates as an independent factor. A simple comparision between the maps of the climatic and soil zones establishes the significant role of climate.

#### *Plant and animal organisms*

The role of plant and animal organisms in soil formation is also important. The plant kingdom consists of *macroflora* of trees, shrubs, and grasses, and *microflora* of bacteria and fungi. Dead plants provide *humus*, which is the dead organic matter in the soil. Humus sustains other forms of life, changes the appearance of the surface soil, helps in the weathering of minerals, and accelerates soil formation.

The activities of both bacteria and fungi are related to climatic conditions. Bacteria consume humus. In cold climates bacterial activity is limited. Hence, humus collects

on the soil. In humid tropical and sub-tropical climatic areas bacterial activity is intense and humus is consumed. Hence, these soils tend to be poor in humus. Also, the organic acids formed by humus are absent and undissolved aluminium, iron, and manganese accumulate in large quantities in the soils making them infertile. Bacteria also change the gaseous nitrogen of the air into a chemical form which can be consumed by plants. This process is termed *nitrogen fixation*.

The influence of animals is termed *faunal*. Three faunal groups are recognized—microfauna, mesofauna, and macrofauna. Micro-organisms such as protozoa, reduce organic debris to their elements, promote mineral exchange, and make nitrogen available to plants. Mesofauna comprises worm-like animals in soil and they number billions per hectare of soil. They live in soil water and help in improving aeration and mixing mineral and organic matter. They consume plant debris, bacteria and fungi, and reduce the humifying material to a small size and then move it deeper into the soil. Macro-fauna comprises woodlice, earth worms, ants, termites, rodents, and birds. The agents re-work the soil by burrowing and change its texture and chemical composition. In many areas the soil is rearranged by the bringing of lower horizons to the surface and the downward movement of the surface soil into lower horizons.

#### Geomorphic factors in soil formation

Geomorphic factors such as relief slope, weathering processes, and aspect to the sun influence the formation of soils. On steeper slopes the soil is thinner than on gentler slopes. On flat upland areas a thick soil is formed, often with a good

layer of clay, but it is largely leached. Flat bottom lands in the flood plains have a poorly drained, dark coloured, thick soils. They usually have a surplus of humus. On gentle slopes new soil derived from the parent material balances the soil which is removed by slow erosion.

Time is the third passive soil-forming factor. Soils develop in the course of time and experience changes in their properties over time.

There are three relative stages of soil development, young, mature, and old. The young stage is characterised by the dormant control of the parent material and invading organisms. The soils of the young stage evolve from recently deposited river alluvium and glacial till. They are poorly developed and do not have the characteristic horizons. The mature stage reflects a greater influence of climate and these soils are developed over a long period of time. It has a well-developed profile of horizons which remains constant through time. The old soils mostly occur in the tropical regions and are one to six million years in age.

#### Process of Soil Formation

The process of soil formation includes several physical, chemical, and biological processes. They operate at different rates in different environments. Two major processes operate in the formation of soils : (i) the accumulation or formation of parent materials, and (ii) the differentiation of horizons.

Accumulation of parent materials is effected by physical and biochemical weathering. Physical weathering results in the mechanical breaking down of rocks. Chemical weathering involves many other changes : oxidation, hydration, hydrolysis

and carbonation.

After the parent material is formed, three sets of processes operate on it to convert it into soil - physical, chemical, and biological. Their effect on the formation of soil horizons is termed *horizon differentiation*.

In the upper parts of the parent material which is subject to both mechanical and chemical weathering as well as biological processes, there occurs an accumulation of vegetation litter and subsequently of humus. Humus gives the soil a dark colour in the upper horizon. The roots of the plants extract the nutrient elements from the depths of the parent material and on their death become mineralised in the form of compounds. The compounds are changed into a soluble form. Part of this solution is absorbed in the upper humic horizons and part is carried down by water to the zone of activity of plant roots. Thus, just below the humus, the rich top horizon (A-1) there is the zone of eluviation, (horizon A-2). This is succeeded at a lower depth by the zone of illuviation, (horizon B). From A-2 colloids and bases are leached out and deposited in horizon B. Below horizon B is horizon C of weathered parent material. This is succeeded by horizon D which is the underlying rock.

#### **Physical and Chemical Properties of Soil**

The physical and chemical properties determine both the fertility and productivity of soils. The physical properties include texture, structure, and colour.

*Soil texture* refers to the particle sizes composing the soil. These particles are classified as gravel, sand, silt and clay in

decreasing order of size (Fig. 22). Each soil type is really a combination of various proportions of these particles. Four textural types are recognised. These are sand, sandy loam, loam and clay. All the textural types are combinations of different sizes of particles. Sand contains 80 per cent or more of sand, and 20 per cent or less of silt or clay. Sandy loam contains 20 to 50 per cent silt and clay and remainder sand. Loam contains 20 per cent or less of clay and 30 to 50 per cent of sand. Loam is termed silty loam where silt predominates and clay loam if clay predominates. Clay contains 30 per cent or more of clay and 70 per cent particles of other sizes. Soil texture determines the water condition of the soil by affecting the pore space size. In sand as both the particles and the pore spaces are large, it drains rapidly. The particles and pore spaces in clay are small, hence drainage is very slow. Both are poor for plant growth for which loam texture is best.

*Soil structure* refers to the arrangement in which soil grains are grouped together into larger pieces. Major types of structure are blocky, granular, columnar, prismatic, crumb, and platy. Soil structure influences the absorption of water by the soil, its erodibility, and ploughing.

*Soil colour* is a minor physical attribute but it is the most readily observed. It indicates the origin and composition of the soil. Increasing quantities of humus produce a range from white, through brown, to black. Black and dark brown colours are typical of soils in the cool and humid areas of temperate latitudes. Soils in the steppe lands and deserts are light brown and grey. Red and yellow colours

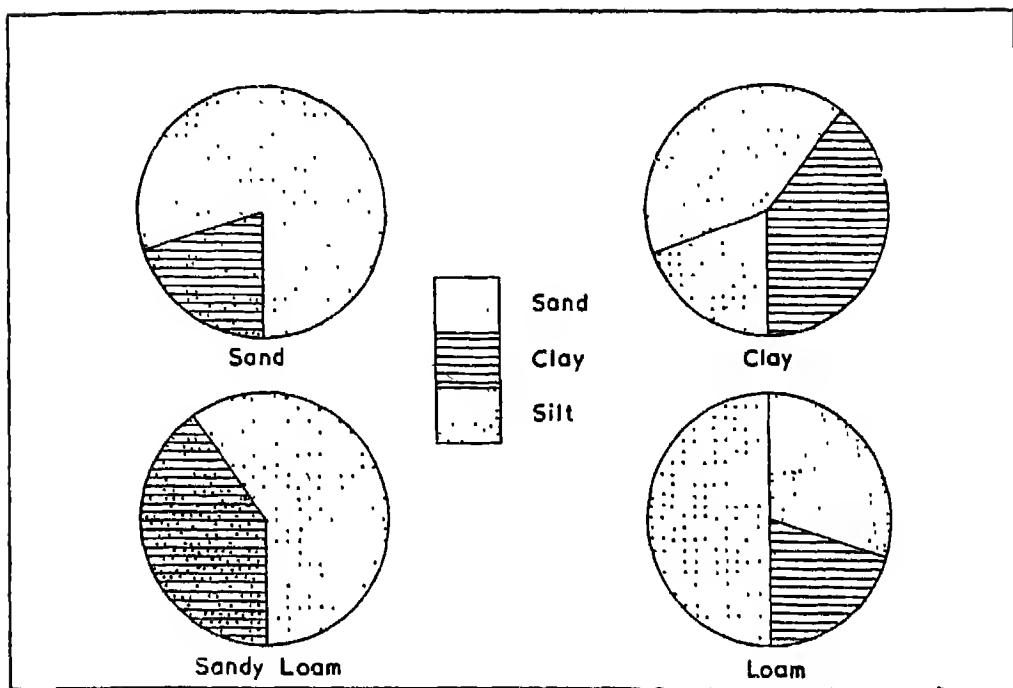


Fig. 22. Main Textural types of soil

are quite common and both are due to the presence of iron oxides and hydroxides,

*Chemical properties* of soil include soil water, chemical composition, soil colloids, humus and soil air.

*Humus*, an important chemical constituent of the soil, is the non-living organic matter. It is developed through the slow oxidation of vegetative matter. Humus gives a dark brown or black colour to the soil and its particles hold ions in the soil.

*Soil air* occupies the pore spaces of the soil when it is not saturated with water. It contains an excess of carbon dioxide but there are only small quantities of oxygen and nitrogen.

The physical and chemical properties of the soil vary not only over space but at

one site also along the vertical. This results in the formation of *soil profile*. The soil profile refers to the arrangement within a soil of its horizontal layers termed horizons. These horizons are differentiated in terms of texture, colour and consistency. A soil profile is formed mainly of three horizons. A and B represent the true soil, and C is the sub-soil or weathered parent material. Below this is the bedrock horizon D.

#### Soil classification

Soils are classified into groups or types on the basis of some selected characteristics.

There can be three systems of soil classification (i) empirical based on certain physical properties, (ii) morphologic based

on the nature of soil profiles and (iii) genetic based on the known formative and environmental factors involved. These three systems have been combined. Here the properties of horizons and genetic factors have been combined to identify the morphological characteristics.

Zonal soils are those which occur over large areas or climatic zones having geographical characteristics of their own, sited on well-drained undulating land, having well-developed profiles and other properties, developed on parent material which has remained in its original place for a sufficiently long time to have been affected by climatic and organism processes. *Zonal soils display a characteristic latitudinal belt distribution.*

#### *Zonal soils*

The zonal order is comprised of soils which can be differentiated on the basis of humid and arid, semi-arid, and sub-humid climatic zones. Thus we have two climatically originated classes within the order of zonal soils (Fig. 23).

In the humid climate class we have *podzol*, grey, brown podzolic, red-yellow podzolic, *latosols*, and *tundra soils*.

The *podzols* are the most widely distributed of the zonal soils of the humid climates. They occur in the sub-arctic climatic and northern parts of humid continental climate areas. They develop under conditions of a cold winter and an adequate precipitation spread throughout the year.

*Grey-brown podzolic soil* occurs in humid climates. The profile of this soil is similar to that of the *podzolic soil*, but leaching is less intense and the colour is brownish. Its physical and chemical properties are

similar to those of the *podzols* but less pronounced in their expressions. Agriculture on it is highly productive. They are good for diversified crop farming and dairying. Eastern U.S.A., the North European Plain, and the Northern Chinese Plains are typical areas of its occurrence.

*Red-yellow podzolic soil* occurs south of the grey-brown *podzolic belt*. There is a general similarity in its properties with those of the *podzols*. But the humus content is low and iron hydroxides give typical red and yellow colours. In warm, humid, tropical areas this soil contains large quantities of aluminium hydroxides. Pine vegetation is associated with this soil also. South-eastern U.S.A. is a typical area of its occurrence. *Latosols* or lateritic soils are characteristic of the humid tropics. Their characteristics include the complete chemical and mechanical decomposition of the parent rock, complete leaching of silica, a reddish-brown colour given by the oxides of iron, aluminium and manganese, and a complete lack of humus. The soil has few plant nutrients, hence, it loses its fertility quickly, when brought under cultivation. The soil is associated with luxuriant rain forests of hardwoods, and lianas. In the top horizons there is an accumulation of iron and aluminium oxides which is used in making bricks. The material is called *laterite*. On weathering, *laterite* becomes extremely hard. *Laterite* gives *bauxites*, *limonite*, and *manganite*. India, South-east Asia, the Amazon Basin, and the Congo Basin are typical areas of occurrence.

The *Tundra soil* is widespread and co-extensive with the Tundra climatic and vegetation type. Hence it is a *zonal type*,



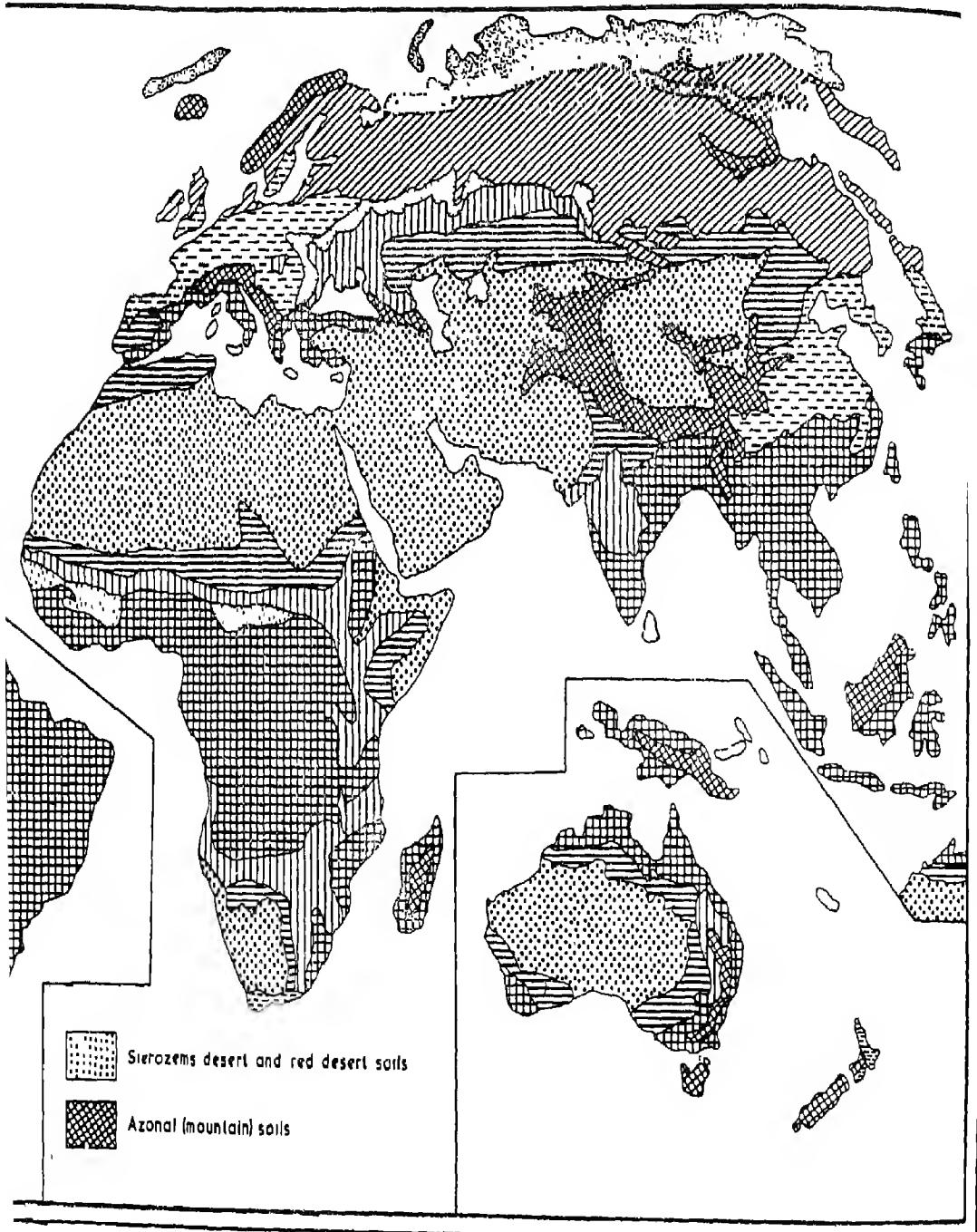


Fig. 23. Main Soil Types

but as it is poorly drained, it can be considered to be intra-zonal. Excessive humus is another characteristic. There is no distinctive profile but there are thin layers of clay and humus. It is an acidic soil.

Arid, semi-arid, sub-humid zonal order soils include chernozem, chestnut, chestnut-brown, grey desert, and red desert varieties. They occur in areas in increasing order of temperature and aridity.

*Chernozem* is associated with a continental, warm, moist early summer, later summer and winter drought, and dry snow-free winter climate, and long-grass steppe. In the profile, horizon A is black, deep, and mineral-organic, horizon B has clay accumulations and C horizon is calcareous. Horizon A is rich in humus while horizon B in colloids and bases. The chernozem is generally acidic. A typical area of its occurrence is Ukraine but it is also widespread in the Central U.S.A., Central Africa, South America, and Australia. Chernozem is highly productive for small grain crops, such as wheat, oats, barley, and rye. The Ukraine 'the bread-basket of the U.S.S.R.' is in fact based on chernozem soil. Very similar to chernozem is the prairie soil.

*Chestnut soil* occurs towards the arid side of the chernozem belt in the semi-arid middle-latitude steppe lands of North America and Asia. Its profile is similar to that of the chernozem but it contains far less humus and has a prismatic structure. There is a lot of alkaline organic matter. High agricultural yields are possible only through the application of soil-moisture conserving techniques.

Chestnut soil is replaced by Chestnut brown type in more arid areas which is very similar to the former, but has less

humus and a lighter colour. The soil is typical of the middle-latitude steppes and is suitable for livestock grazing.

*Grey-desert soil*, also termed *sierozem*, occurs in vast east-west belts between 30° and 50°N latitudes in the Northern Hemisphere. It is co-extensive with the spread of the middle-latitude desert climate. The principle characteristics of this soil are little humus, slightly differentiated horizons, and a hard, resistant deposit of calcium carbonate termed caliche.

*Red-desert soil* has the minimum humus. The red colour is imparted by small amounts of iron compounds. A coarse texture, poorly developed horizons, fragments of parent rock, and deposits of lime carbonate are characteristic properties.

Desert soils are suitable for cultivation along the flood plains and on the terraces where their texture is fine.

#### **Soil erosion and soil conservation**

The process of destruction of soil and the removal of the destroyed soil material constitute soil erosion. Moving water and wind are the two principal agents of soil erosion.

Water moves on the surface in two forms, as a sheet, and in a line. The former is termed sheet movement and the latter, linear or *channel flow*. Sheet movement causes sheet erosion and channel flow causes linear erosion. In both forms of erosion by water, two controlling factors are important—the velocity and the quantity of pronounced surface run-off and the erodability of the soil itself. The nature of the slope, the texture of surficial material, the amount and nature of incident precipitation, and the vegetation cover directly affect the surface run-off.

The erodability is influenced by the inner properties of the soil, texture, structure, consistency, and cohesiveness. On a gentle slope, adequately clothed by a vegetation cover, clay soil will resist erosion to a great extent. On such a soil, channel erosion will succeed but not sheet erosion. Here ploughings are done across the contour lines. On such a sloping surface, the ridge and furrow surfaces are created, the furrows then act as channels and the soil is quickly and massively eroded. Everywhere natural vegetation restricts the extent and the intensity of soil erosion.

Sheet erosion removes the upper genetic horizons of the soil over extensive areas. This is followed by channel erosion in the form of gulleys and ravines. Valuable cultivated land is changed into wasteland.

Wind erosion also termed *deflation*, occurs in dry climatic areas having a sparse and low vegetation cover on mechanically weathered, loosened surfacial material. Dust storms are the principal agents of wind erosion. Fine silt and clay in dry friable form are removed from the surface, thus, eroding the top horizon and rendering it infertile. Wind deposits sand in some areas masking the existing soil and rendering it unproductive. On the whole, wind plays a destructive role with no redemption, unlike the river which both destroys and recreates.

Methods by which soil is prevented from being eroded constitute soil conservation. Soil conservation has an urgent significance throughout the world because of the slow rate of soil formation. In tropical and humid temperate areas for example, one centimetre deep soil is formed during about 200 and 150 years respectively. Soil

erosion, on the other hand, can take place within a short time.

All methods of soil conservation ultimately have to aim at reducing the amount and velocity of surface run-off and of the erodibility of the soil. The cover of the vegetation not only reduces the surface run-off, but also binds the soil particles through the roots and increases its strength. Thus, vegetation cover protects the soil from the attack of erosional processes. The planting of forests has been the most important of the soil conservation techniques. The planting of forests in areas from where the original vegetation has been removed by man is termed reforestation. The planting of forests in those areas which have never had any vegetation is termed afforestation. Both reforestation and afforestation are needed more specifically on slopes where trees retard the surface run-off and bind the soil.

On the slopes which have been transformed into a series of terraces, the walls have to be reinforced by lines of trees, and boulder and stone embankments. The terraces break the flow of surface run-off and act as wells of deposition of eroded and transported sediments. Contour bunding, terracing and contour ploughing, thus, protect the soil from being eroded.

For conserving soil in the aeolian geomorphic areas tall plants are grown as wind-break sows at right angles to the wind direction.

An indirect passive measure is to prevent the slopes from being grazed intensively by sheep and goat and other livestock. Overgrazing causes a packing of the soil and decrease of its water permeability.

SOILS  
EXERCISES

1. Define soil. How is it different from rock ?
2. Describe a typical soil profile.
3. How are the horizons in a soil profile formed ?
4. Name separately the active and passive factors of soil formation.
5. What is humus ? How is it formed ? What is its significance in soil formation ?
6. Why are the soils of the humid tropical areas poor in humus ?
7. What is the contribution of parent material to soil formation ?
8. What is the most significant difference between the black soil of Maharashtra and the black soil of the Ukraine ?
9. Why are the main soil types of the world spread in latitudinal belts ?
10. What is the basic difference between sheet and linear surface run offs ?
11. Do you agree that soil erosion is mostly the result of human interference with natural ecological conditions ? Why ?
12. Identify the contributions of foresters and civil engineers in soil conservation plans

**Books for further study**

- Bunting, B.T., *The Geography of Soil*, London : Hutchinson & Sons, 1965.  
Jenny, H., *Factors of Soil Formation*. New York : McGraw-Hill Co., 1941.  
Jacks, G.V., *Soil*, London : Nelson, 1954.  
Plyusnin, I.I., *Reclamative Soil Science*, Moscow : Foreign Languages Publishing House, 1965.



## CHAPTER 8

# Exogenous processes in the Evolution of Landforms

**E**xogenous processes of landform evolution and landform changes are those which derive their energy from external sources and ultimately from the sun. These processes are mainly caused by earth geomorphic agents, such as river, wind, glacier, and sea-waves. Exogenous processes include gradation, degradation, aggradation, and weathering.

### Gradation

Due to crustal movement and unequal erosion and deposition the surface of the earth in its various parts becomes irregular. By and large, these irregularities constitute the surface topography of the earth. The geomorphic agents such as river, glacier, wind, and sea-waves, remove the material from the higher parts and deposit it in

the lower parts. Gradation is the process by which the original irregularities of the earth's surface are removed and a level surface is created (Fig. 24). Gradation starts operating as soon as irregularities are created and continues until these are fully removed. The processes of gradation derive their energy ultimately from the sun, but immediately from atmospheric phenomena. All gradation processes are directed by gravity. Gradation is accomplished by the twin processes of degradation and aggradation.

### Degradation

*Degradation* constitutes those processes by which material from a high relief feature is removed by exogenous or external processes and the main geomor-

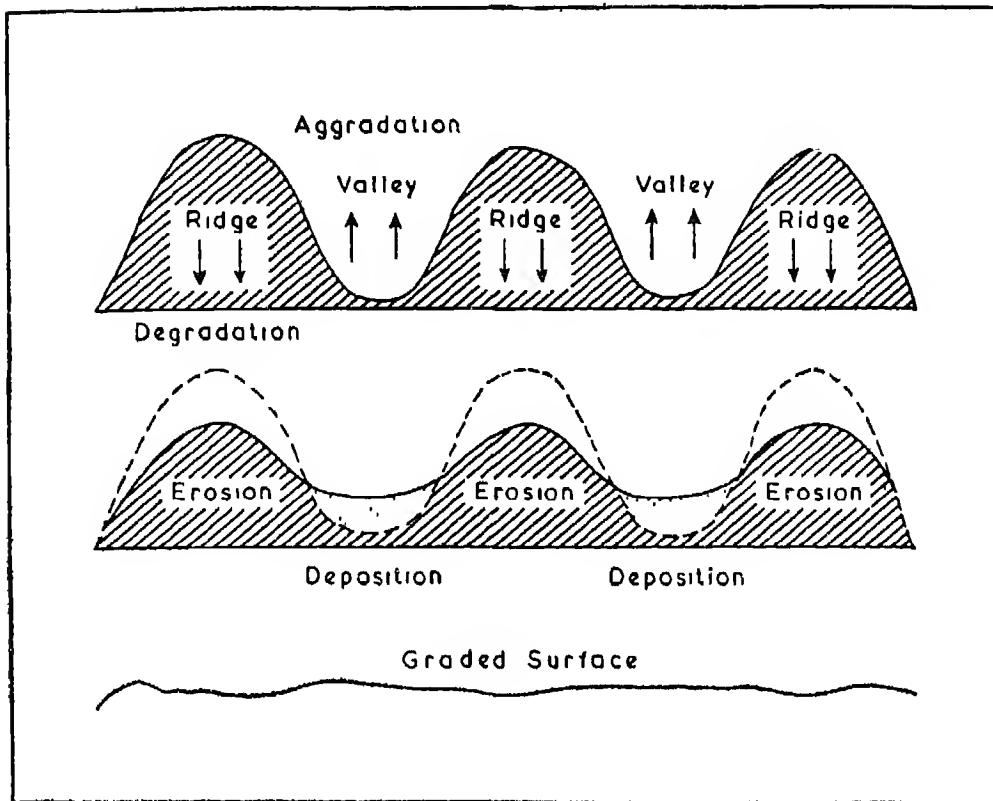


Fig. 24. Formation of graded surface by Aggradation and Degradation

phic agents (Fig. 24). Bed rock is removed through erosion, and weathered product from the bed rock is transported away. Degradation by removing material from the high relief features reduces their elevation. Degradation is controlled by three factors - the properties of the material on which the processes are operating, the energy available to the geomorphic agents, and the tools used by the agents. Where the materials are easily erodable, and the agents have large energy and large amount of tools, the efficiency of degradation is very high. A stream in

the hills does the work of degradation efficiently. It is necessary to remember that degradation is only the removal of material from high relief features. There are necessary conditions which must be fulfilled before degradation can take place. The rock must be in a form that can be eroded, necessary competence is acquired by the agent, and the agent must have tools.

Degradation comprises of three processes: weathering mass-wasting, and erosion. Weathering is the disintegration or decomposition of rock *in situ*. It is a

static process and does not involve any movement. Mass-wasting involves the bulk transfer of masses of rock debris down slopes under the influence of gravity. Landslides are examples of mass-wasting. Earthflows in mudflows are other examples.

### Weathering

As defined earlier weathering refers to the disintegration or decomposition of rocks in place. Weathering helps erosion but is not a part of it. There can be weathering without erosion and erosion without weathering.

There are two main types of weathering : physical and chemical. Both are affected by rock structure, climate, topography, and vegetation.

Rock structure refers to mineralogical composition, joints bedding planes, faults, fractures, pores, and its integral hardness. The minerals control the rate of chemical weathering. The joints permit water to enter the rock and achieve chemical and physical weathering. Climate determines whether physical or chemical weathering will predominate and the speed with which these processes will operate. Topography directly affects weathering by exposing rocks and indirectly through the amount of precipitation, temperature and vegetation. Topography also determines the aspect or direction which exposes the rocks to the direct attack of rain or wind. Surfaces covered with vegetation are protected, and bare surfaces are weathered to a greater extent. Since, even within small areas a large variety of bedrocks are exposed to the processes of weathering, differential weathering is quite common. *Physical weathering* is also termed

mechanical weathering. This process refers to the mechanical disintegration of rocks in which their mineralogical composition is not changed.

Igneous rocks are formed at great depths under conditions of high temperature and pressure. When they appear on the earth's surface as a result of the removal of the overlying rocks, the pressure on them is also removed. This results in the expansion of igneous rocks and in the formation of large scale fractures parallel to the surface topography. Sheets between the fractures are detached from the main mass which thus suffers fragmentation. This process is termed *exfoliation*. It results in the formation of *exfoliation domes*.

Crystal growth results in expansion and rock fracturing, water enters the rocks through fractures and joints and then freezes. Crystals are formed, and when they expand the joints are enlarged. Repetition of this process results in the weakening of the rocks and ultimately their fragmentation. This process is termed *frost heaving*. It operates more efficiently on the rocks which initially contain a large number of joints, fractures, and bedding planes. In the middle and high latitudes, ice crystals are very effective when there is a repeated freeze and thaw. Growth of other crystals, such as salines, formed in dry climates through capillary action of water containing salts in solution, also forces the rocks to expand and thus cause fractures leading to fragmentation.

Repeated thermal expansion and contraction as a result of alternate heating and cooling results in the weakening of the rock. Creation of joints and fractures and

enlarging of the existing ones, and finally to the disintegration of the rocks. This is termed *mass exfoliation*. In the rocks containing minerals which expand unequally there is granular exfoliation or disintegration. Spheroidal boulders are formed by these processes.

Plant roots also penetrate the rocks, create new fractures and enlarge the existing ones.

Chemical weathering is more important than mechanical weathering in almost all the climatic regions. Chemical weathering results in (i) an increase in volume which produces stresses within the rocks (ii) lower density materials (iii) particles of smaller size which produce a larger surface for chemical interactions, and (iv) more stable minerals. There are two end products of chemical decomposition and disintegration :

(i) residual, such as clay and (ii) soluble, such as calcium bicarbonate which can be removed in solution.

**Oxidation** When a rock is exposed to atmosphere, the atmospheric oxygen present in rain water enters into chemical union with its constituent minerals, especially the iron compounds. This results in the decomposition of the rock leading to its crumbling into a powdered mass. This is known as oxidation. The original colour of the rock is also changed into red, yellow, or brown. This process is similar to the rusting of iron or steel in the presence of air and water, as a result of which the metal crumbles to a brown dust.

**Hydration** The chemical union of water with a mineral is called hydration. The process of hydration is particularly effective on some aluminium-bearing

minerals such as felspar. On its chemical combination with water, the felspar swells or increases in volume, as a result of which its outer shell gets detached by the mechanical force of expansion. The product left behind is a residue of sand and clay.

**Carbonation** Rain water, in the course of its passage through the atmosphere, dissolves some of the carbon dioxide present in the air. It thus turns into a weak acid (carbonic acid) which acts on limestone rocks. This process is known as carbonation and is well noticed in the limestone or chalk areas in the humid regions of the world.

**Solution**—Some of the minerals may also be dissolved by water and thus removed in solution, for example, rock-salt and gypsum. This process of chemical weathering is known as solution.

**Process of removal** : Products of physical and chemical weathering are removed by the following geomorphic agents : running water, groundwater, waves and currents, wind, and glaciers. Each of these agents acquire loosened rock material i.e., load. This loosened material in transit abrades i.e., rubs against the surface. In transit the moving material also gets worn and ultimately the material in movement gets transported and deposited elsewhere.

The two processes by which earth surfaces are eroded by materials in transit are corrosion and corrosion.

The geomorphic agencies carry tools with them. The boulders, pebbles and sands are transported by them. These are the tools. When these tools move on the earth surface or rock surface these surfaces are corraded or abraded. Formation of

pot holes in river beds is an example of corrosion or abrasion. In many rivers of peninsular plateau in our country we see such pot-holes. Corrosion is removal of material by solution. Wearing of materials while in transit is known as attrition. The movement mutually, tub, grind, knock, materials in scrape, and bump. This results in reducing their size. The material acquired by the geomorphic agents is transported (Fig. 25) by rolling, pushing and dragging along the surface. This is known as traction. Often rock materials move forward by leaps and bounds in saltation. Turbulent currents of air and water hold the moving small rock materials in suspension. Rock materials also get embedded in glaciers and are carried forward.

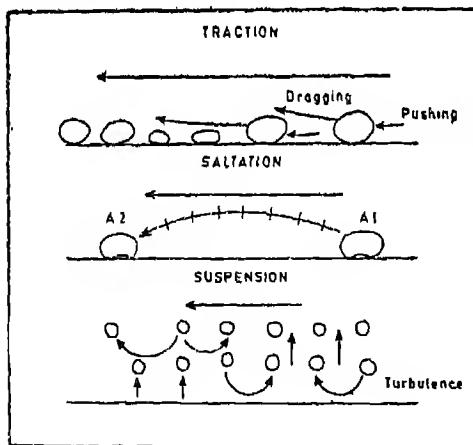


Fig. 25. Traction, saltation, suspension

Aggradation is a consequence of degradation. It contributes as greatly as degradation to the general levelling of the earth's surface. Aggradation means deposition and accumulation. In general, deposition results from the loss of the transporting capacity of the geomorphic agent. This happens when either the

velocity is reduced or the material being transported exceeds the capacity for transporting. Underground water carries limestone in solution. When this solution evaporates, precipitates are formed. This is a special type of deposition. Usually, depositional features have a limited extent and are not easily shown on topographical maps.

In general, few landform features are either entirely degradational or aggradational. Most features are subject to both the processes. A plain is formed not only by deposition but also by erosion operating at the same time. The processes of erosion, transporation and deposition take place in a river simultaneously in its different stretches.

#### Cycle of erosion

The concept of cycle of erosion was formulated by William Morris Davis. His major objective was to describe and explain the distinctive characteristics possessed by landforms. He suggested that these were related to the stages of their development. In a cycle of erosion the surface forms undergo changes as a result of the processes acting upon them. These changes are not erratic but follow each other in a regular sequence. These sequences are termed stages. According to Davis there are four stages: initial, youth, maturity, and old. However, most commonly, only youth, maturity, and old stages are used in the description and study of topographies produced by different geomorphic agents (Fig. 26). In the initial stage the landform is generally even and is raised high above the sea level, slow and small changes occur. However, vast changes take place by the time the landscape attains maturity. In the old stage

again landscape evolution slows down.

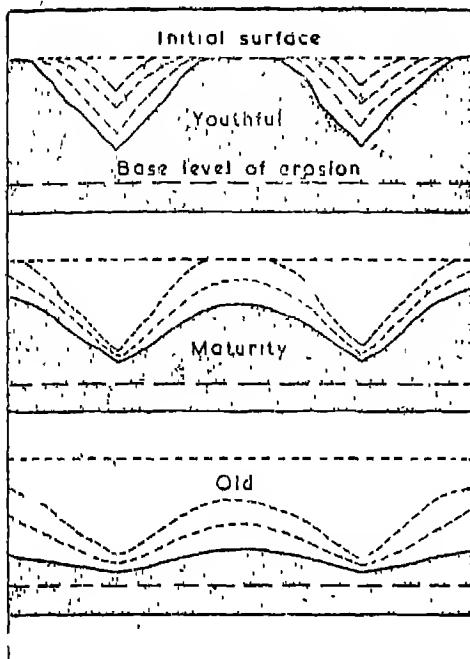


Fig. 26. Cycle of Erosion

Different geomorphic agents have their characteristic cycles of erosion. Thus, we have, *fluvial cycle of erosion*, *glacial cycle*, *aeolian cycle*, *karst cycle* and *marine cycle of erosion*. Mature, and old stages characterise all the cycles of erosion. But, however, the evolution of landscapes and their stages are significantly different.

In the initial stage the relief is small. Hence, the mobile geomorphic agents work slowly and the material removed is likewise small. Topography is simple and the number of landform features is small. Most of these features are erosional in origin and small in extent.

In the mature stage relief features become bolder, with marked contrast in hill and valley forms.

The old stage is characterised by a general loss of energy of the geomorphic agent. Now, the topography is much subdued and tends to be lowered to the base-level of erosion. This is the level to which the initial relief is lowered. High relief features are worn down and low relief features are filled up or aggraded up. Thus, there is a general levelling of the topography. Peneplains and monadnocks or inselbergs are highly characteristic features of this stage. The peneplain is broad low, generally smooth-outlined plain which represents the completion of a cycle of erosion. Monadnocks or inselbergs are residual still features which resist erosion because of their hard constituent rocks.

Thus, the cycle of erosion envisages that landforms evolve through a definite sequence of stages. The cycle operates through the three stages until the initial relief is almost fully reduced and the surface is again levelled.

Most of the cycles of erosion do not reach the final stage as some time during their operation either climatic or tectonic disturbances take place. An incomplete or partial cycle results from this. Topography returns to a youthful stage. This phenomenon is termed *rejuvenation*. In it, a mature topography becomes young i.e., it is rejuvenated. The cycle of erosion begins anew.

#### Fluvial topography

Fluvial topography or the normal cycle of erosion (i.e., cycle of water erosion) was formulated by Davis. He also applied it to the understanding of glacial, karst as well as aeolian topographies. In his opinion, these three topographies are merely the deviations from the normal cycle of erosion. Hence, fluvial topography is the

most important of all topographies.

The main features of the fluvial cycle are :

The cycle begins on a recently uplifted landmass. It is initiated through the drainage system working on it.

The initial landmass is sculptured and reduced by the combined action of weathering, mass-wasting, and erosion both by streams and surface run-off of water.

According to Davis, a rapid uplift of the landmass is followed by a long period of standstill or quiescence. During this period of standstill the cycle of normal erosion operates fully or completely.

However, during the period of standstill, a cycle may be completed only partially, when another uplift initiates a new cycle. Thus, many incomplete or partial cycles may result.

The three stages—youth, maturity, and old—can be recognised in the normal cycle. These follow each other in a regular sequence.

Each stage is characterised by a distinctive set of landscape features.

Structure, process, and stage are the three factors which explain the land forms produced in a cycle.

The initial landmass can be completely worn down to a level below which erosion is not possible. This is termed *base-level*.

In the old stage at topographic surface of low relief termed *peneplain* is created.

Fluvial topography develops well in a drainage basin. In the drainage basin the streams join each other and with a trunk or master stream. The joining of the tributaries with the master stream produces a pattern termed *drainage pattern*. The common drainage patterns are dendritic,

parallel, trellis, and radial (Fig. 27). A *dendritic* pattern resembles a tree in which the angles of confluence of the tributaries with the master stream are small. A *parallel* pattern develops on steep slopes where the tributaries and the master stream flow parallel to each other for considerable lengths before meeting each other. A *trellis* pattern develops in a topography created on a folded structure of synclines and anticlines. Anticlines are breached and the more powerful synclinal valley streams capture others of their kind flowing at a higher level. Such stream junctions are almost at right angles. A *radial* pattern consists of drainage lines radiating from a central part as on a dome.

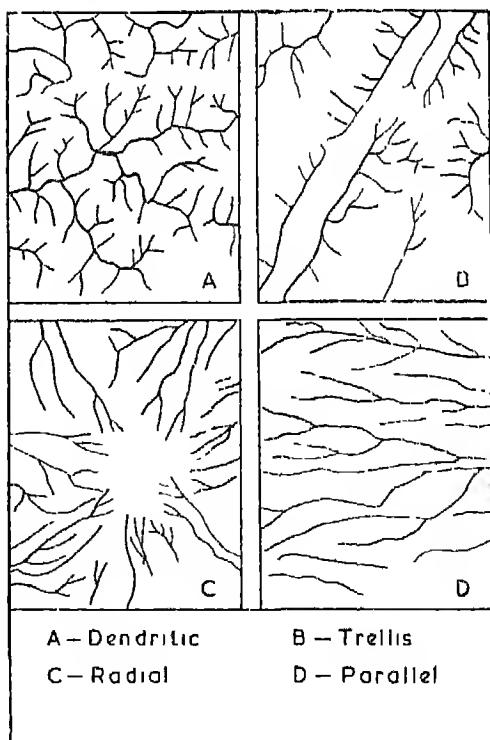


Fig. 27. Drainage Patterns

### Youthful Topography

In general a youthful topography is associated with a recently uplifted landmass. It may be a plateau, folded range, or inclined beds, with some relief features. The work of the river through erosion, transportation, and deposition is of a significant order. In the youthful stage the elevation of the landmass is the highest (Fig. 28).

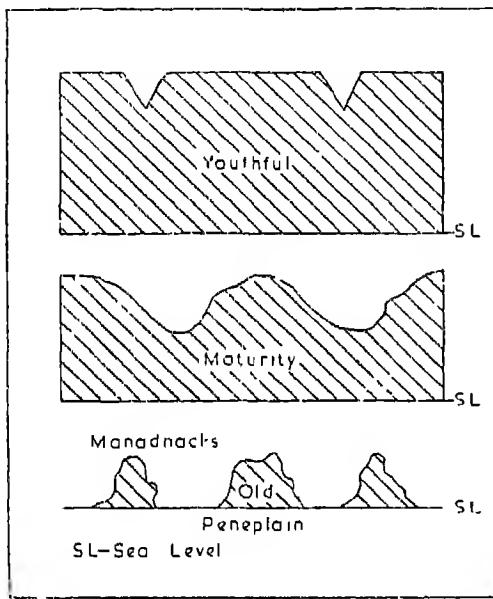


Fig. 28. Fluvial Cycle

Some of the characteristic processes in this stage are channel deepening due to bed scouring and pot-hole drilling, formation of V-shaped valleys. The interfluvial divides are wide and generally simple in their outlines. Finger-tip tributaries, extended gullies, headwater, amphitheatres, semi-circular crests, waterfalls, rapids, valley headwalls, and inter-locking spurs are some of the other features characterising this stage.

Waterfalls (Fig. 29) develop spectacularly

and ideally at the sites where there are escarpments or very steep slopes and the faces are composed of very resistant, horizontal beds. Vertical joints help the formation of scarps on which the rivers form the waterfalls. At the base of the waterfalls the churning of water containing boulders produces pot-holes, the process being known as *pot-hole drilling*.

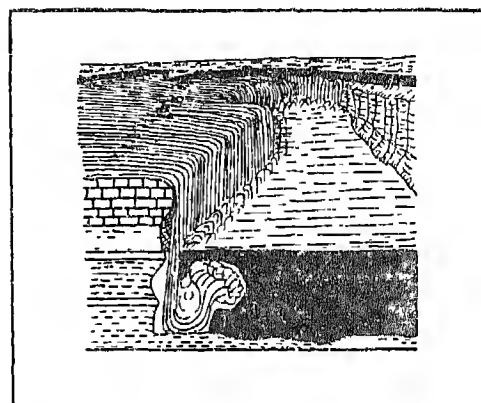


Fig. 29. Niagara Fall

### Mature Stage Topography

This stage is characterised by maximum relief and maximum erosion. Drainage lines now get integrated in a density network. The landmass is fully dissected. Ridges and valleys develop strikingly. Rivers flow with a graded profile (Fig. 30). During this stage both erosional and depositional activities are at their maximum. This can be contrasted with the youthful stage in which there is only a little erosion, and with the old stage which is characterised by an enormous amount of deposition. As a result of heavy erosion and deposition the mature stage topography is comprised of a large number of landform features. Such are hogbacks, cuestas, plateau tables,

esplanade meanders, meander cut-off or ox-bow lakes, meander core, meander scar, natural bridge or arch, flood plain, flood plain scarp, river bluff, terraces, alluvial fans, and linear lakes.

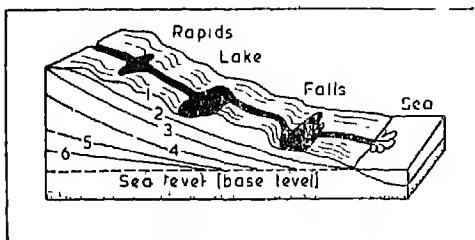


Fig. 30. Gradation of a Stream

The flood plain and its associated features and meanders are the most typical of this topography (Fig. 31). Floodplain is formed by repetitive deposition, beyond the banks, of material brought by the floods of the rivers. It is wide, long, and parallel to the river. On the floodplain the characteristic features are natural levees which are long depositional ridges extending parallel to the river, abandoned channels, ox-bow lakes, and linear lakes.

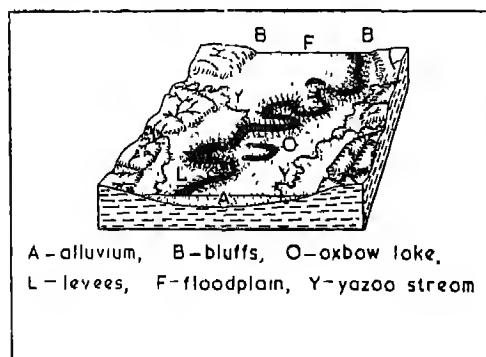


Fig. 31. Landforms of an Alluvial River Flood Plain

The meandering of the channel streams produces a S-shaped channel form (Fig. 32). It is caused by irregularities in the

flow of water and in deposition on the bed of the river. As the meandering becomes more accentuated the ends of the loop come nearer and eventually meet. When the loop is detached from the main channel and ceases to receive water from it, an ox-bow lake is formed. The mouth of such a lake is sealed by clay plugs. After the ox-bow lake is filled up by deposits and water disappears, the feature produced is *meander scar*. The land enclosed within the meander loop is termed *meander core*.

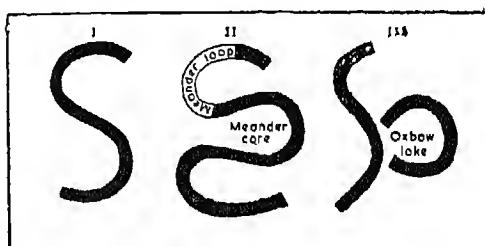


Fig. 32. Stages of Meandering and Formation of Ox-bow Lake

On descending to the plains from the hills the velocity of a river and hence its carrying capacity are reduced. At this point the river sheds a large amount of load which assumes a fan or conical shape

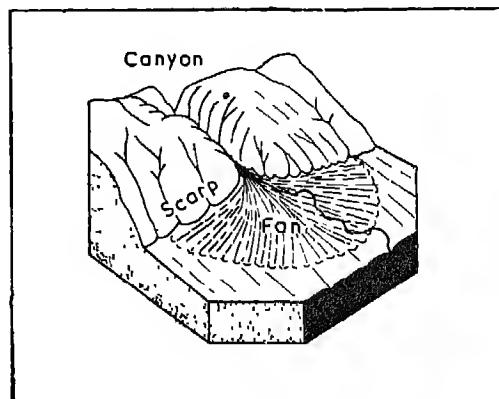


Fig. 33. Alluvial Fan

(Fig. 33). This is termed *alluvial fan*. In the lower parts many fans join laterally to produce a *bajada* or *piedmont* plain.

A little further down the river cuts into the material deposited by itself, creating a feature which consists of several steps. These step-like plains are *terraces* (Fig. 34). The terraces are separated by steep wall-like escarpments. Terraces occur on a small-scale along the meanders and in the flood plains as well.

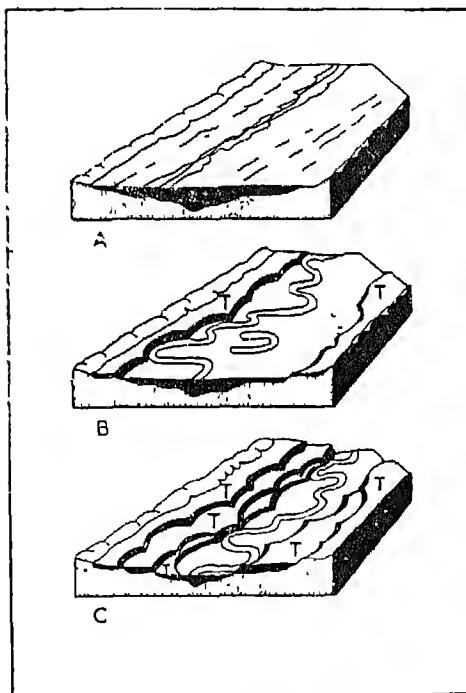


Fig. 34. Alluvial Terraces

In the mature stage the main streams have well-developed valleys separated by inter-fluvial divides (Fig. 35). The valleys are bounded by river bluffs which overlook the flood plains. Near the base of the bluffs are located linear lakes which represent the inactive flood plain scour routes through which the diversion

channels had flown at one time. At places the natural levees are breached by channels originating from the main river and then flowing on to the flood plains. Where they cut the natural levees they are termed crevasse channels and afterwards flowing parallel to the main channel they are termed yazoo streams.

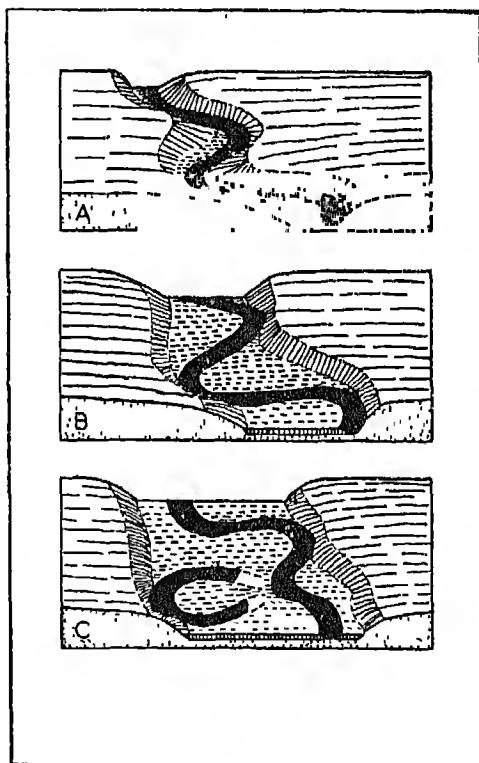


Fig. 35. Widening of a valley by lateral cutting of a Stream

Along various sections during this stage the main channel splits into many narrow wet channels separated by lenticular sand or gravel bars (Fig. 36). The splitted channels again meet the main channel somewhere downstream. This happens due to the shedding of a large part of the extra load that the river cannot carry. The

channel is then termed *braiding*.

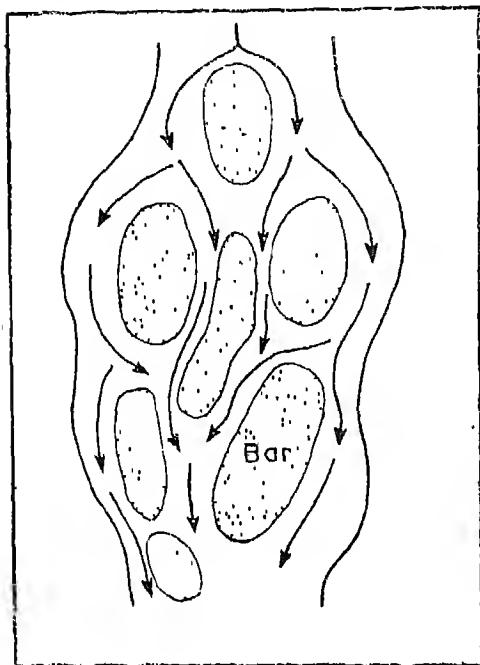


Fig. 36. Braided Stream

#### Old Stage Topography

In this stage the rivers are flowing very near to their mouth level which is the sea-level. The gradients are gentle, the velocity is low, and the energy of the river flow is small. Hence, the river is mostly engaged in depositing and does little of erosion and transportation. The relief of the topography is small and the outline of the land is gently rolling with very wide valleys and low inter-valley divides. Most of the surface is covered with clay or silt.

The topography is characterised by a set of distributional features which comprise delta, distributaries, delta-flank depressions, linear depressions, lenticular sand bars, and saucer-shaped interfluves.

The delta (Fig. 37) is the most widespread

depositional feature and characteristic of the old age topography. It is triangular in outline and mainly formed of an enormous volume of deposition of finer particles near the mouth of the river.

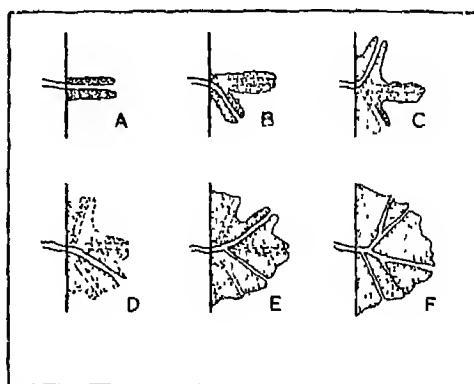


Fig. 37. Stages in formation of a Simple Delta

Through the delta run a large number of channels which come out of the main channels. These smaller channels are termed distributaries or passes. The distributaries are wide but shallow, choked with silt and clay, and extremely sluggish.

Depressions filled with water and forming lakes occur on the flanks of the deltas. These are termed delta-flank depressions such as Lake Manzala in the Nile Delta and Lake Kolleru in Andhra Pradesh. Linear depressions with stagnant water or just abandoned and dry are termed *bil* in Bengal. They are the residual parts of the distributaries. Lenticular, long bars composed of sand and clay are termed *char* in Bengal. Natural levees, ridges formed by the deposition of material over-spilled by the flooded rivers are quite common in the deltaic areas. Natural levees are long features and run parallel to the rivers.

### Aeolian Topography

Aeolian topography is created by the erosional and depositional processes of wind in the arid zones of the world. Hence, it is also termed arid zone topography (Fig. 38).

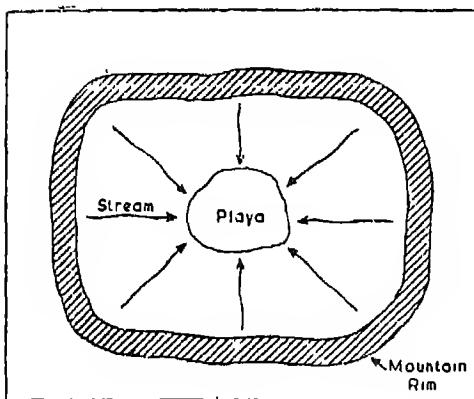


Fig. 38. Intermontane Desert

Wind creates its characteristic topography by three processes, abrasion, deflation and deposition. *Abrasion* is the sandblast action of wind with sand against the rocks. Attrition is the grinding action in which wind is the force and sand is the tool. Abrasion does not produce any landform feature of significant size. It is effective near the ground and upto a height of about 50 cms. *Deflation* is the process of wind transportation. *Deposition* comprises sedimentation, saltation and surface creep, and encroachment. Abrasion shapes features like yardang, tabular mounds with hard rock cap, pedestal rocks (Fig. 39), and caves and niches. Desert pavements, desert polish, and horn-shaped sand are typical features produced by deflation. The most typical features of sand are dunes and loess which is a thick deposit of wind-blown silt. In the arid zones,

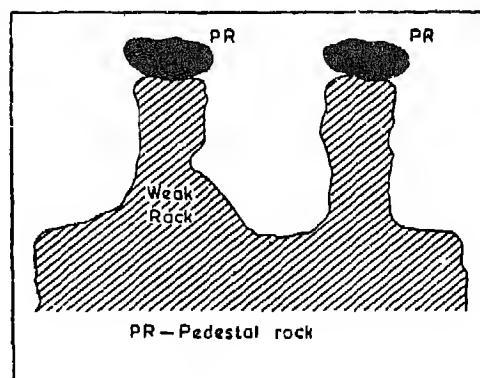


Fig. 39. Pedestal Rock

topography is influenced both by wind and by action of rivers and sheet flows of water. Such features are playas as centres of inland drainage basins of flat surface, desert flats, alluvial fans, bajada, pediment (Fig. 40), desert plains, hammadas, badlands, and inselbergs.

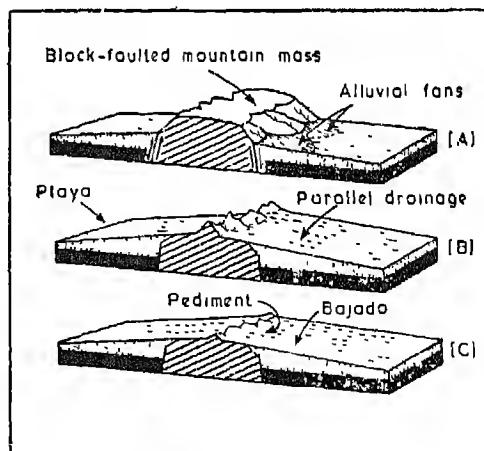


Fig. 40. The Erosional Evolution of a Pediment

### Glacial topography

Davis suggested that a glacial topography is a climatic accident that happens to normal cycle of erosion i.e., climate gets

very cold and the rivers freeze. Instead of rivers of water there are rivers of ice, called glaciers, operating as the main geomorphic agent.

Glacial topography has the following basic characteristics : It is parasitic in nature. Glacial topography is developed on a pre-glacial topography. Hence, it is also classified as compound or composite topography. It is limited in area, in distribution, and in time. The largest extent was attained during the Pleistocene or Great Ice Ages. Now, the glaciated topography is limited to the very high, young, fold mountain regions, such as the Himalayas, Andes, Rockies and Alps. There is no control of base-level exerted on the reduction of relief in glacial topography. The rate of relief reduction is extremely low. This is due to interruptions in the cycle caused by advance and retreat of glaciers. The movement of glaciers is by reelevation i.e., pressure within the ice-mass and hence the effects are felt by both sloping and flattish areas. Peneplain is unknown in glacial topography.

A glacier is a large natural accumulation of ice which reveals evidence of present-day or past movements. Glaciers originate in snowfields or neves. They move down the pre-existing valleys or radiate out in great lobes.

Glaciers acquire loosened material by scouring, gouging, plucking or sapping. They erode the earth's surface by corrosion and gouging. Through attrition the particles in transit are reduced in size. Glaciers transport material through traction and suspension.

Evidence of past glaciation is provided by (i) striated, grooved, and polished

surfaces, (ii) lack of residual soils, (iii) large volume of glacial deposits, eskers, and moraines, (iv) glacial deposits comprised of unweathered rock, and (v) numerous rock basins.

#### Types of Glaciers

There are two major types of glaciers, the valley glaciers and the continental glaciers or ice sheets. Correspondingly, there are two types of glacial topographies, one related to the valley glaciation and the other to the continental glaciation. The two topographies are characterised by distinctive features.

#### *Topography of Valley Glaciation*

There are two sets of features resulting from glacial erosion and glacial deposition (Fig. 41),

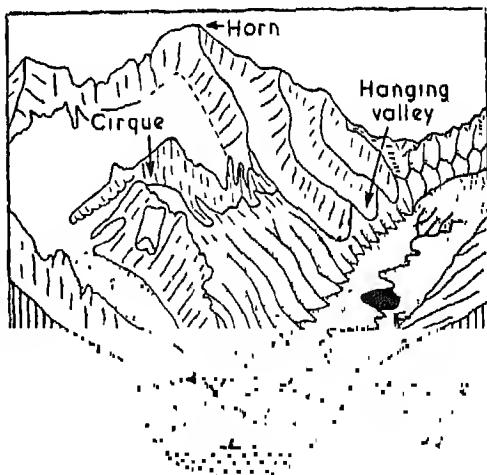


Fig. 41. Glacial Features

**Features of Erosion :** Features of glacial erosion include *cirques* which are circular depressions formed by plucking and grinding on the upper parts of the mountain slopes. They are the most widespread features of mountain or valley glaciation.

Another feature is known as *glacial trough* which is the well-known U-shaped valley.

A *hanging valley* is formed where a glacier carves out a deeper U-trough and the tributary valley is left perched on the high wall of the U-trough. The junctions of such valleys are the sites of waterfalls. Fjord is a drowned U-shaped valley along the coast. It is deeper toward the coast where it is overlooked by a high, bold cliff.

*Features of deposition:* In the valley glaciated topography there are the following typical features.

*Moraines* are formed by the deposition of the valley glaciers (Fig. 42). Three types of moraines are known, lateral, medial or median, and terminal or end.

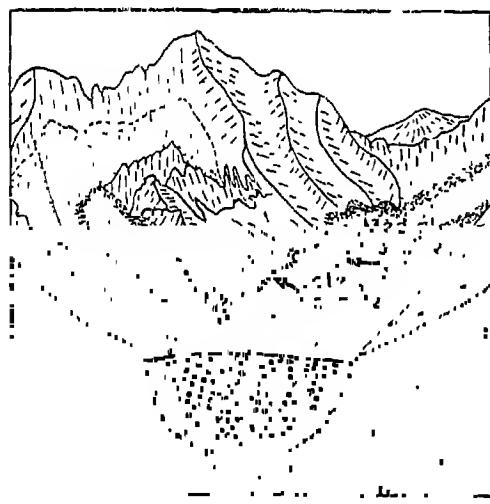


Fig. 42 Medial and lateral Moraine

These three types are differentiated on the basis of their location in the valley. Where glacier retreats in a halting manner, a series of concentric moraines is formed they are termed recessional or stadial

moraines. Moraines form long ridges after the disappearance of glaciers. The moraine formed on the bed of the valley is termed ground moraine. Glacio-fluviatile features are produced by the deposition of melt-water channel load after it emerges from under the glacier. Valley-shaped trains are formed along the bases of the high walls of the U-valleys. They appear as terraces beginning from the end moraines and extending down the valley. Esker is a sinuous ridge of assorted, stratified sand and gravel. It is produced by the filling of melt-water channel and is exposed after the glacier disappears. Kame terrace is an ice-contact feature in which the deposits are laid against an ice-surface. It is formed by the filling of depressions between the glacier and the sides of the trough.

Glacio-lacustrine features are related to those which are produced by lakes and glaciers. Lakes are quite common in such a topography. A lacustrine plain is formed by the filling up of the various types of glacial lakes. They have flattish surfaces.

#### *Topography of Continental Glaciation*

In this topography, the features of erosion are the ice-scoured plains, sheep rocks, and rock basins. The features of deposition include : till plains ground moraines, terminal moraines, drumlins the glacio-fluviatile features, such as kames and eskers, tunnels, outwash plains, and the glacio-lacustrine features, such as lakes and the lacustrine plain (Fig. 43).

The ice-scoured plains are extensive areas developed on hard bedrock surfaces. Sheep rocks are the most common features. These are composed of hard rocks and have a shape of half-egg. They

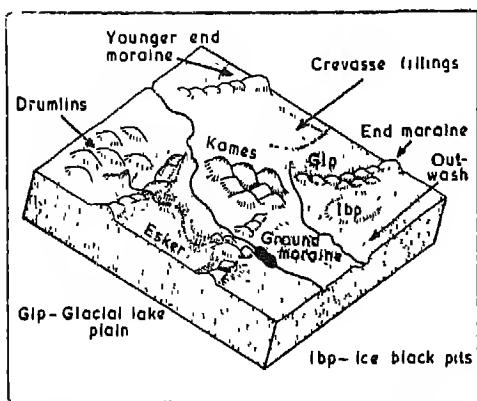


Fig. 43. Continental Glacial Features are formed in a series and cover extensive areas. Finger-lakes are long depressions and are also formed in series.

A *till plain* is produced where pre-glacial

topography is buried. Till material is highly heterogenous and is unstratified. The ground moraine reveals a swell-swale topography corresponding to the knob-and-basin topography. The terminal moraine reveals a knob-and-kettle topography in which the knobs are hills and kettles are depressions. Drumlins are half-ellipsoid in shape and like inverted spoons. Many drumlins occur parallel to each other. Drumlins are formed by glaciers clogged with drift or till material over-riding their own load.

Many of the glacio-fluviatile and glacio-lacustrine features of continental glaciation bear a close similarity to with those of valley glaciation.

## E X E R C I S E S

1. Explain the relationships existing between degradation, aggradation and gradation.
2. What are the two main types of weathering? What are their basic characteristics?
3. How is erosion different from weathering?
4. Name the main geomorphic agents. Which of these agents is the most important?
5. What are the fluvial processes of erosion, transportation, and deposition?
6. How does a glacier erode?
7. Attempt relating cirque with horn in glacial topography.
8. Why does aeolian topography contain so few topographic features?
9. What is a cycle of erosion?
10. Describe the stages which constitute the normal or fluvial cycle of erosion.

**Books for further study**

- Bloom, A.L. *The Surface of the Earth*, New York : Prentice Hall, USA, 1969.
- Dury, G.H., *The Face of the Earth*, London : Penguin, London, 1959.
- Lake, *Physical Geography*, London : Cambridge University Press, 1958.
- Thornbury, W.D., *Principles of Geomorphology*, New York : John Wiley, 1969.
- Worcester, P.G., *A Textbook of Geomorphology*, New Delhi · East-West Press 1965.
- Morisawa, M., *Streams*, New York : McGraw Hill, 1968.
- Sparks, B.W., *Geomorphology*, London : Longmans, 1960.



## CHAPTER 9

# Endogenous Processes in the Evolution of Landforms

A process which originates within the earth's crust is termed endogenous. Although it originates within, it does affect the earth's surface in a spectacular manner. Mountains, plateaus and volcanoes are some of the striking features produced by endogenous processes. The two main endogenous processes are *volcanism* and *diastrophism*. The geomorphic features produced by them provide the setting for exogenous processes to operate upon. All features which owe their origin to an endogenous process are invariably modified by exogenous processes. A folded crust consisting of synclines and anticlines is eventually changed by river erosion into a topography of ridges and valleys. What we observe on the

earth's surface are mainly the features carved by exogenous processes.

Diastrophism elevates or builds up portions of the earth's surface. This prevents the exogenous processes from ultimately reducing the earth's land areas to sea level. Diastrophic processes are classified as *orogenic* and *epeirogenic* (Fig. 44). Orogeny refers to mountain-building, with deformation of the crust and the earth's surface. Epeirogeny refers to regional uplift without marked deformation. Orogenic movements are far more localised than the epeirogenic, and involve tangential forces resulting in compression. Orogenic movements occur in episodes, widely spaced in geologic time, and are world-wide in extent.

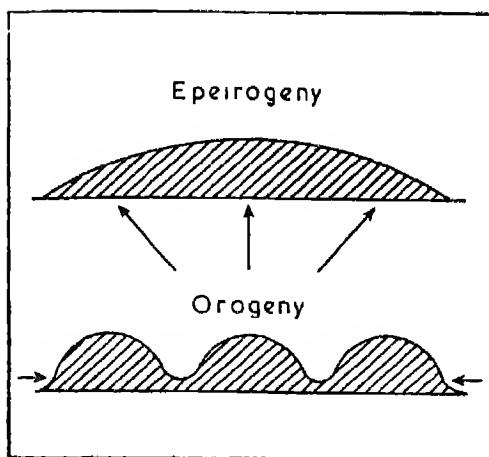


Fig. 44. Epeirogeny and Orogeny

During the long intervals between two consecutive periods of orogeny, the earth's crust remains stable or subject only to slow epeirogenic uplift or subsidence. It is during these stable periods that the ideal geomorphic cycle or cycle of erosion can operate fully. Epeirogeny is a vertical and orogeny, a horizontal earth movement. Vertical movement is mainly caused by radial forces, the forces that operate at right angles to the earth's surface. Vertical movement is either uplift or subsidence. Upwarping and downwarping are the two results of the vertical movement. Orogeny is *tangential* in that the movement is parallel to the earth's surface. Both compression and tension, pushing in and pulling out, lead to horizontal movements.

Warping and isostasy cause vertical movements while folding, faulting, and continental drift constitute horizontal movements.

### Folding

The bending of rock strata due to compressional forces acting tangentially

or horizontally towards a common point or plane from opposite directions is known as *folding* (Fig. 45). It results in crumbling of strata into folds. The compression is usually applied from one direction in mountain-building. The fold is on a great scale and the exposures of

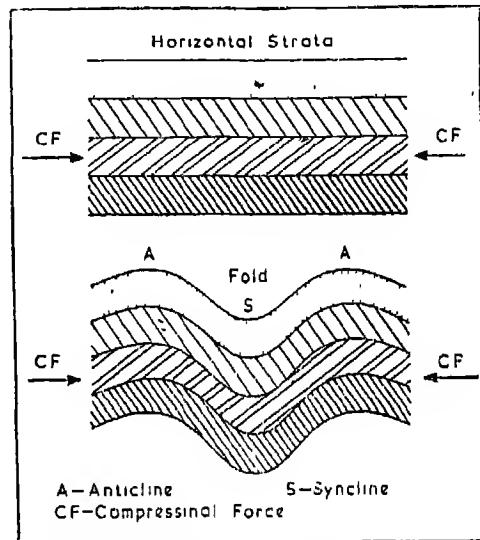


Fig. 45. Horizontal Strata and Compressional Force

rocks are discontinuous. Folds occur in a series of troughs and crests alternating with each other. The upfolds are termed *anticlines* and the downfolds, the *synclines*. Thus, anticlines and synclines are the features of structures on which the topography of ridges and valleys is developed. Folding is sub-divided into *compression* which leads to contraction, and *tension* which results in extension. The two more common features of folding are anticlines or synclines. Like the waves of a lake surface, the rock folds also comprise alternating crests or troughs. The crests are the upfolds or anticlines, whereas the troughs are the downfolds,

The more striking landforms of the folded structure are anticlinal ridges, anticlinal valleys, synclinal valleys, synclinal ridges, homoclinal ridges, homoclinal valleys (Fig. 46) and water gaps. Anticlinal ridges correspond with

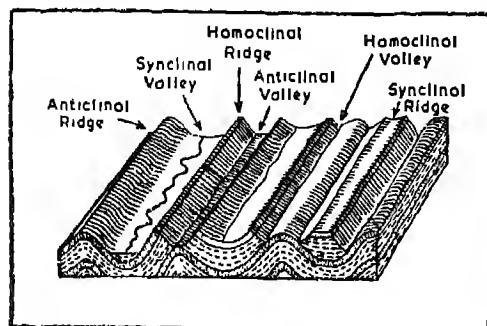


Fig. 46. Valleys in Relation to structural formation

anticlines. On the crest of the anticline, along the axis from where the limbs dip away, is a zone of tension and, therefore, of weakness. The rivers flowing here breach the anticline and gradually erode the material and deepen the valley. Where the anticline is fully eroded the ridge is replaced by a valley. This is termed *anticlinal valley*. It is an example of what is commonly known as *inversion or relief or topography*. So are the syndinal ridges. The sides of both these features correspond to very steep, scarp slopes. Synclines correspond to valleys. Between two anticlinal valleys the synclinal portion stands higher than the valleys. This is termed a *synclinal ridge*.

### Faulting

Fault is a fracture of large magnitude along which the broken crustal blocks have been displaced with reference to each other. Displacement occurs parallel to the plane of the break. Fault is the ultimate

result of vast regional tension. Every fault must have two components, the fault plane and the displacement (Fig. 47). The fault plane or the fault surface is the break along which displacement takes place. The fault plane makes an angle with the horizontal plane which is termed *dip* of the fault. The angle made by the

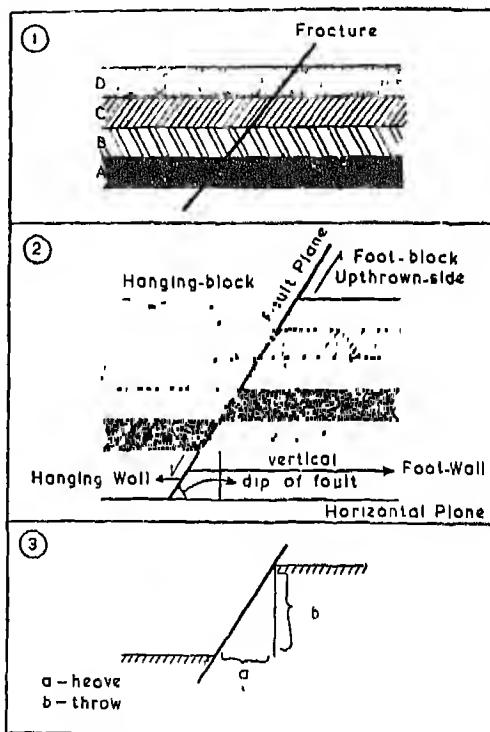


Fig. 47. Fracture and Fault Plane

fault plane with the vertical is termed *hade*. Thus hade and dip are complementary angles. The part above the fault plane is known as the *hanging block* and the one below it is termed the *foot block*. The surface of the hanging block on the fault plane is the *hanging wall* and that of the foot block on the fault plane is the *foot wall*. Displacement is of two types, the

vertical displacement termed *throw* and the horizontal displacement termed *heave*.

The types of features related to faults are scarps of several types, horst, graben block mountain, and rift valleys.

Scarp is the most characteristic feature produced by faulting, both normal and reverse. Generally, scarps are associated with high angle faulting. A fault scarp is modified considerably by the erosion of exogenous processes. Such scarps however, are quite high and often display steep slopes. At the base of the scarp are located small *alluvial cones* or *talus cones* composed of coarse material. Scarps are also the sites of hanging valleys and strikingly developed waterfalls. Where the previous rocks on one side of the fault plane are juxtaposed with the impervious rocks on the other side, a line of springs generally emerges.

Horst or a block mountain is an uplifted landmass located between two adjacent faults (Fig. 48). A graben or rift valley is the block lowered between two adjacent faults. The rift valley of East Africa and the Vosges and the Block Mountains of Europe are good examples of rift valleys and block mountains.

In certain faulting the ridges are breached to allow the streams to cut through. The gap is termed *watergap*. Where the streams cross the faults, they display lateral offsetting. Locally giant landslides are also associated with transcurrent faults. The transcurrent faults have great significance in the understanding of the theory of Continental Drift.

#### Warping

Warping is deformation of the earth's crust but one which does not necessarily involve folding. Warping affects very

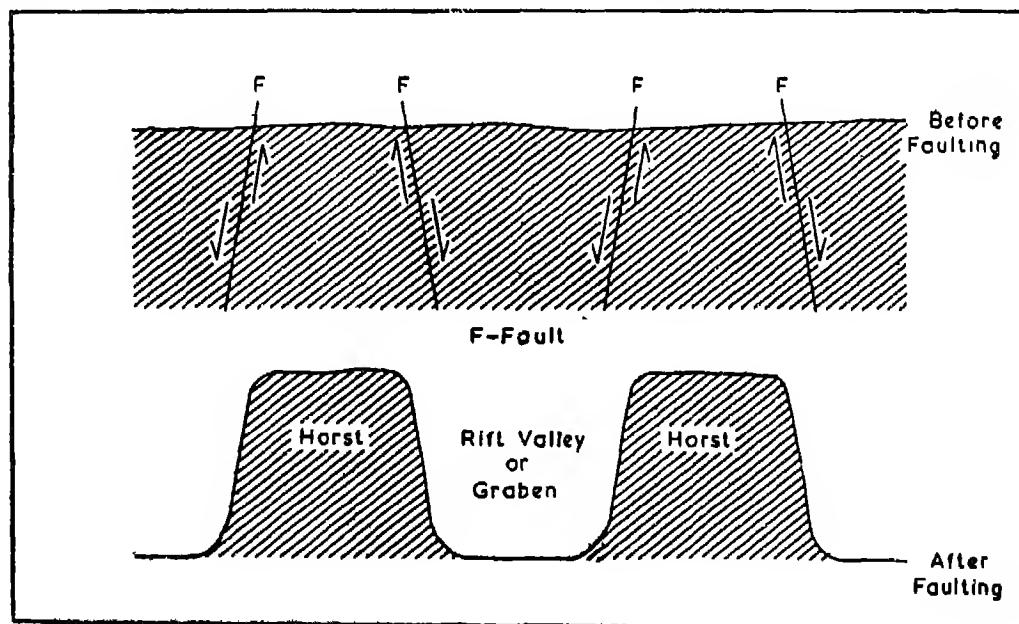


Fig. 48. Formation of Horst and Graben

large areas on the earth's surface, and thus results in the formation of *domes*, *shields* and *depressions*.

There are two types of warping : upwarping and downwarping. Upwarping is caused by vertical upthrust exerted, for example by a laccolith on the overlying bed (Fig. 49 B). Since the pressure exerted is maximum at the centre, and becomes less and less with the increasing distance from it, the central part is raised far more higher than the peripheries. As a result, the crust assumes a vast domal or shield shape. In downwarping, the crust is buckled down by the pressure exerted vertically down by the enormous load of deposition (Fig. 49 A). In both upwarping and downwarping the beds need to be elastic to be raised up or down, otherwise the thrust would break the crust and domes or depressions would not be so well-formed.

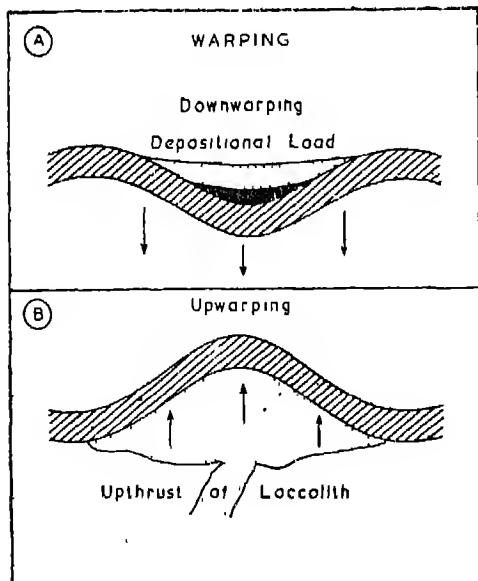


Fig. 49. Downwarping and Upwarping

**Isostasy.** All large land masses on the earth's surface rise or sink. After a geologically adequate time period, these land masses tend to get adjusted. This adjustment leads to a hydrostatic equilibrium. Equilibrium is upset in those areas where there are local stresses. Isostasy refers to the state of hydrostatic balance. Isostasy, therefore, is neither a force nor a process. It is a condition of gravitational balance between crustal segments of different thickness. Isostasy also refers to a tendency toward restoration of balance once it has been disturbed by some other force or process. But this isostatic balance is never fully achieved. When the crustal segments are in an isostatic balance the high and lowlying relief features of the earth's surface are also in a state of balance. This is made possible by the fact that the high relief features have lighter materials in them, while the large, low relief features, such as ocean basins, have heavier materials under them. This enables the maintaining of a condition of mechanical stability on a rotating earth.

The state of isostasy can be maintained only if there is a continuous *compensation* at depth. Through erosion, material is being removed from the tops of the mountains which, therefore, are becoming lighter. Material should therefore, move into the roots of the mountains at depth through the interior of the earth. This movement is termed compensation.

Isostatic movements are always vertical. These are related to the processes of erosion and deposition on a large scale and to glaciation on a fairly large scale (Fig. 50).

Load is shifted on the surface from high

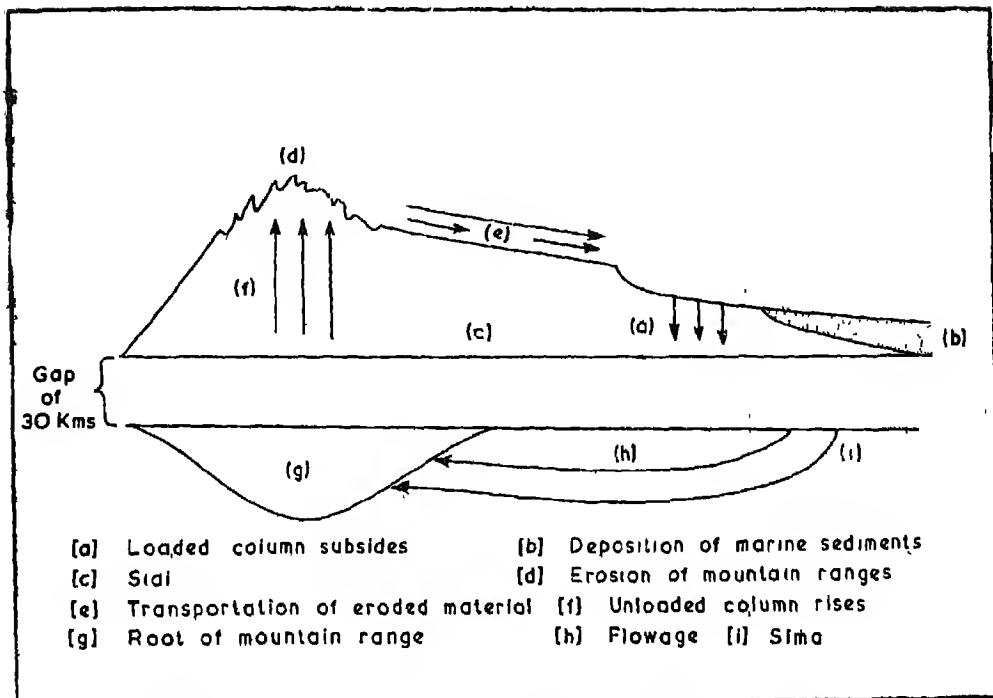


Fig. 50. Isostatic Movements in Relation to Erosion and Deposition

relief features to lower areas. This is balanced by mass transfer at the bottom of the crust or beneath it.

### Continental Drift

Continental drift refers to the horizontal movement of the continents on a vast scale. Wegener was the first to advocate the theory of Continental Drift. According to him, the continents drifted apart from each other in the remote geological periods. There is geological evidence to show that in the past geological periods equatorial, tropical, and arctic climatic types were located in latitudes far removed from their present-day location.

According to the theory of Continental Drift, all the sialic layer was concentrated

in a large continent called the *Pangea* before the Silurian period (270 million years ago). This block floated, in a universal basaltic layer. The basaltic layer is located below the *Conrad discontinuity*, with a probable depth of more than 17 kms. In the late-Palaeozoic period (200 to 500 million years ago), probably during Permian (200 to 235 million years ago) or Mesozoic (70 to 200 million years ago) era, the *Pangea* broke into pieces under the influence of the tidal force and the force generated by the movements of the earth's axis of rotation and revolution. (Fig. 51).

The southern parts of the *Pangea* broke apart during Mesozoic and the northern

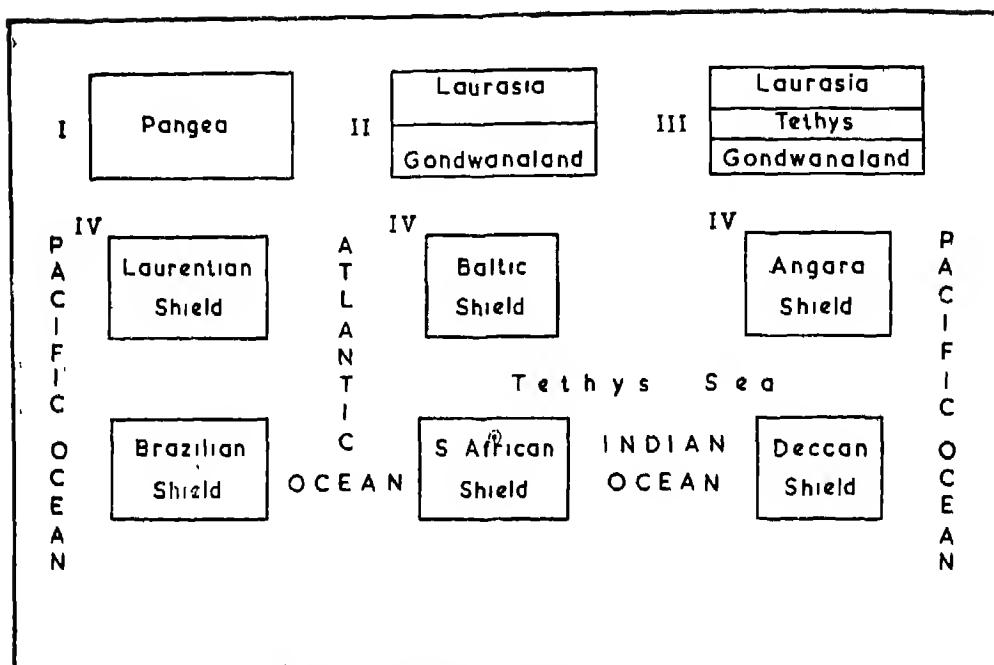


Fig. 51. Sequences in Continental Drift.

in the Tertiary periods (2 to 70 million years ago) Fig. 52. The Continental Drift was caused by differential gravitational forces which acted upon the protruding block of sial. One force caused the drift towards the equator and the other towards the west. The African block (the Gondwanaland) and the Eurasian block (the Laurasia) moved towards the equator. When the drift towards the equator was taking place, the Americas drifted to the west. Thus, the Atlantic Ocean was created between North and South America in the west and Europe and Africa on the east. Australia was left behind in the beginning. Later, it swung to the east. Only recently in terms of geological time periods did Antarctica separate from South America.

Before drifting, North and South America formed one unit. They rotated about a point in North America. Then they were drawn apart. This produced the narrow land of Central America and the scattered fragments of the West Indies Archipelago. Labrador and New Foundland separated from Europe during Quaternary (about 2 million years ago). They swung southwest. Greenland was left behind as a separate block. At the same time the Indian part of the Gondwanaland moved north against the mass of the Asian main continent. It separated from Africa. Madagascar was left behind. By the compression of the Indian part against the Angara shield, the mountain chains of the Himalayas were created.

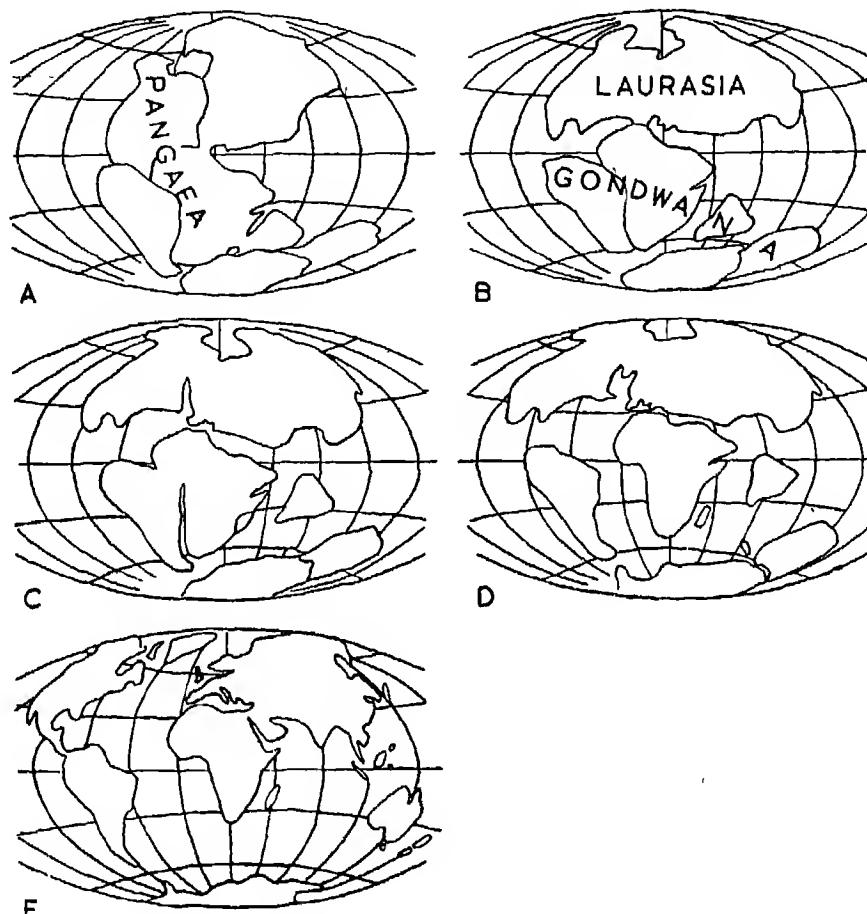


Fig. 52. Continental Drift

Four strong types of evidence have been put forth to support the Continental Drift theory of Wegener : (i) the jig saw fit, which refers to the similarities between the coastlines of South America and Africa, suggests that these were once joined together; (ii) the similarity of pre-

Cambrian (before 500 million years ago) rocks of Central Africa, Madagascar, Southern India, Brazil, and Australia, (iii) the continuity of tectonic trends of the blocks of these countries across their present boundaries, and (iv) the distribution of the fossil plant, in Argentina,

South Africa, India, Western Australia, and Antarctica.

Although the theory of Continental Drift has been widely discussed and accepted, serious doubts have been raised about the period during which the force causing the drift had operated, and also about the direction and the amount of the force. However, the recent theory of plate tectonics, which argues that the continents are moving as plates on a semi-liquid surface, lends support to the theory of Continental Drift.

### Volcanoes

Volcanoes are entirely the product of the forces originating from within the earth. They form some of the most striking features on the landscape.

#### Formation

A volcano is a hill, generally occurring isolated, and composed of accumulation of rocks which were brought from within the earth and then solidified. A volcano is the result of the process of volcanism in which lava is extruded on the surface of the earth. The process arises from the forces which are endogenous in nature and are produced by physical and chemical changes taking place in the earth's interior. In every volcano there is a central opening from which molten material, solid rocks, and gases are ejected (Fig. 53). The lava or the magmatic material originates from the lower parts of the earth's crust and the mantle. Every time the magmatic material is ejected from the opening it spreads around it and gradually cools and solidifies. Thus, around the opening a high landmass is built up. The process of ejection, cooling, and solidification is repeated over long geological period resulting in the formation of the volcano.

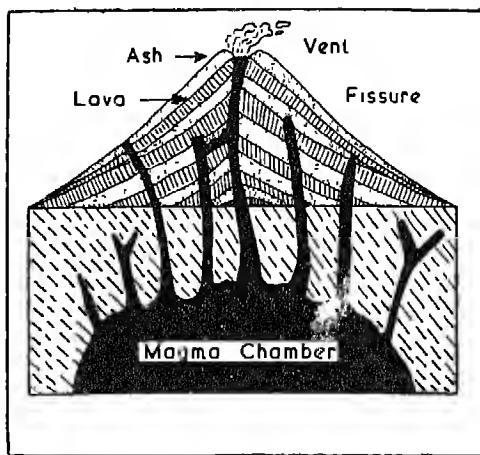


Fig. 53. Volcano

#### Types

There are three types of volcanoes : active dormant, and extinct. The active volcanoes are always pouring forth lava. The dormant ones have been active and inactive alternately within human history. The extinct volcanoes have not experienced any eruption during human history. There are about 500 active volcanoes in the world. Mauna Loa in Hawaiian Island Group is the largest active volcano of the world. Mt. Vesuvius is an example of a dormant and Eifel in Germany of an extinct volcano.

#### Distribution

Even though volcanoes are some of the striking features of the earth, their distribution is very much restricted to a few areas, and some regions and countries do not have any active or dormant volcanoes. India does not have any volcano, either active or dormant, except in the Andaman and Nicobar Islands.

A large number of volcanoes are concentrated in a narrow belt called the Circum-Pacific Ring of Fire which, as

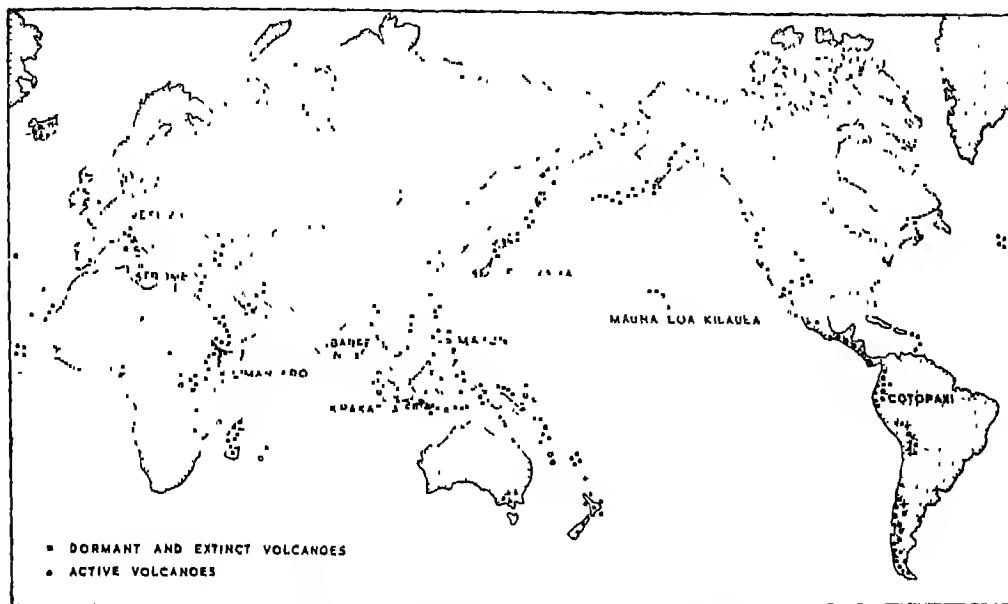


Fig. 54. The Distribution of Volcanoes

the name suggests, is located along the edges of the Pacific Ocean (Fig. 54). Most of the volcanoes in this belt are located on the high, young folded mountains, such as the Rockies, the Andes, the Japanese and Indonesian island arcs. Other volcanic areas include the scattered areas in the Pacific, particularly the Hawaiian Islands, around the part of Indian Ocean, a belt that includes Arabia, Madagascar and the Rift Valleys of Africa, the Mediterranean belt, Azores and Canary Islands, the volcanoes of the West Indies, and those of Iceland.

#### Volcanic Eruption

A volcanic eruption comprises solid, liquid, and gaseous materials. The matter ejected and the manner of eruption are reflected in a variety of forms of volcanoes.

There are two main modes of eruption : quiet and explosive ; and two main types

of materials thrown out : lava and acidic lava. On the basis of location, two kinds of eruptions have been recognised : *central eruption* from a vent and resulting in the formation of a volcanic cone, and *fissure eruption* which produces small cones, lava plains, or lava plateaus.

#### Volcanic Topography

There are two main forms of features of the volcanic topography. The high or elevated relief features include hills, mountains, cones, plateaus or upland plains. The lowlying relief features are craters, calderas, and tectonic depressions. Many of these features are related to each other and occur in the same area. Volcanic cones occur on lava plains, and craters are located on the volcanic cones.

#### Positive Relief Features

Related to four attributes of eruption and erupted material, volcanic features

can be classified into four landscape or topographical groups : such as lava plains or plateaus as in (i) features of quiet eruption and (ii) features of volcanoes or volcanic cones. Basalt domes, or shield volcanoes, are very high and have a broad base and gentle slopes. Mauna Loa in Hawaii is a typical example. Generally, there is a large depression or volcanic sink on the summit which has inward facing cliffs. After the dome is completely dissected, there remains a volcanic stack or neck or plug as a column. Basalt domes also occur in Iceland, Pacific Islands, and Italy. (iii) The ash or cinder cones have many examples in Mexico, Italy, Philippines, and Alaska. (iv) Composite or strato-volcanic cones reveal rough stratification of alternating sheets of lava and pyroclastic materials. These correspond to the alternate periods of explosive and quiet eruptions.

Volcanoes with such cones are the highest and the most imposing. They have symmetrical outlines and concave slopes.  
*Negative Relief Features*

Craters and calderas are the depression forms in the volcanic topography. Crater is a funnel-shaped depression having a circular plan and a neck at the centre. It is rimmed by an infacing scarp. The crater is formed by explosion or subsidence. After an explosion destroys an existing crater, a new but smaller cone with its own crater is built up. This is termed a *cone-in-cone topography*. A crater filled with water is termed a *crater-lake*.

Calderas are very large volcanic depressions. They are also circular in plan, and in diameter they are several times larger than the craters. Calderas are formed by explosion and collapse. A caldera filled with water after the volcano has become extinct is termed a *caldera lake*. The



Fig. 55. Earthquake Belts of the World

Lonar lake in Maharashtra is claimed to be an example of this category.

### Earthquakes

An earthquake is a sudden, temporary motion or a series of motions which originate in a limited region and then spread out from the place of origin in all directions.

The earthquake motion has a definite beginning, it continues for a while and then gradually dies out. It does not die out suddenly. The duration as well as the direction of motion can be estimated precisely with seismographical methods.

### Distribution of Earthquakes

The really destructive earthquakes are

concentrated in a ring surrounding the Pacific Ocean. This ring coincides with the Circum-Pacific Ring of Fire (Fig. 55). The second chain is termed the East Indian. It extends over Indonesia, Andaman and Nicobar Islands, and Burma. The third belt extends over Himalayas, Kun Lun, Tien Shan, and Altai Ranges up to the Lake Baikal. Another belt extends from the Pamir Knot to Afghanistan, Iran, Turkey, Greece, Rumania, Atlas Mountains, Gibraltar, and the Azores Islands. A belt extends from the Gulf of Aden, between Seychelles and Maladive Islands, turns to the west-south of Africa and goes up to the Falkland Islands. A belt also runs along the Great Rift Valley of East Africa.

## E X E R C I S E S

1. What is the relationship between exogenous and endogenous processes ?
2. Why is vertical movement so less frequent than horizontal movement ?
3. What are the types and causes of vertical and horizontal movements ?
4. How does folding take place ?
5. Name the two basic types of folds and describe their properties.
6. What are the two major types of faults ? How are they produced ?
7. What are the three types of volcanoes ?
8. Describe the distributional pattern of volcanoes in the world.
9. How is the condition of isostasy attained ?
10. Define an earthquake, and state what causes an earthquake.
11. Is there any relationship between an earthquake and a volcano ?
12. Describe the salient features of the volcanic topography.

## PHYSICAL BASIS OF GEOGRAPHY

### Books for further study

Hodgson J.H., *Earthquakes and Earth Structure*, New York : Prentice-Hall  
1964.

Leet L.D., *Physical Geology*, New York : Prentice Hall, 1965.

Longwell, C., *Introduction to Physical Geology*, New York : Wiley, 1962.

Thornbury, W.D., *Principles of Geomorphology*, New York : Wiley, 1954.

Sparks, B.W., *Geomorphology*, London : Longsman, 1960.



## CHAPTER 10

# Landforms and their Economic Significance to Man

Landforms are not merely bare natural physical features. They are the settings on which civilisations exist. The major landforms of mountains, plateaus, and plains have different economic significance for man.

### Mountains

Mountains have been recognised as a significant factor in the evolution of civilisation. Mountains have promoted as well as hindered human development. Mountains influence several aspects of man's terrestrial existence by providing him with diversity of physical environments, resources, and political settings.

#### Mountains and climate

Mountains and climate are closely related to each other. The fall of temperature

with the increasing elevation is the cause of this close relationship. The timber line and the snow line in the mountains are due to the changes in climate due to elevation. Both forests and snow have direct and indirect significance as resources of great potential utility for man. Even in the equatorial regions the mountains offer favourable climate for human settlements.

Mountains have their sunny and shady slopes as well as moist and dry slopes, all of which are significant in controlling vegetation, soil erosion, agriculture, and location of human settlements.

The salubrious mountain climate is itself a great economic resource. In order to escape the heat and moisture of the tropical plains, people go to mountains and live in hill resorts. Summer resorts all over the

tropical and sub-tropical world are popular for this reason.

#### *Mountains and Vegetation*

Mountains support a wide variety of vegetation because of the wide variety of ecological settings provided by mountains at various elevations and slopes. Their slopes have different aspects with reference to the sun and winds. This variety is of importance to man. Trees support forestry, and grasslands are used for rearing livestock. Trees also provide some major products, such as timber, and minor products, such as leaves, bark, herbs, and resin. Paper, furniture, rayon, match-box, and sports goods are manufactured from suitable types of timber provided by the mountain forests.

#### *Mountains and agriculture*

Soils of the mountain slopes are thin, gravelly, and eroded; and as such do not encourage agriculture. Lands suitable for cultivation are restricted to man-made terraces. Enormous amounts of labour and investment are needed to construct such terraces as well as to maintain them. In the rain-shadow parts, irrigation is necessary, but it is very difficult to provide. Again, because of the rainfall and particular conditions of temperature, only a specific range of crops can be grown in mountainous areas.

#### *Mountains and minerals*

The old folded mountains consist of enormous masses of igneous and metamorphic rocks. These igneous rocks contain a wide variety of economic minerals. Metamorphism with its heat and pressure produces a large number of economic minerals. Coal, iron, copper, gold, manganese, mica, and diamond are the main mineral reserves that are associated

with the old folded mountains. The young folded mountains, also, possess many useful minerals. Minerals associated with lava are derived from volcanic rocks. Mining and quarrying in mountain lands are difficult. In the old mountain areas, the terrain is highly dissected and has low elevation. Hence, mining and quarrying activities are more widespread in them. The mining of minerals is more important in the Peninsular India than in the Himalayas.

#### *Mountains and hydroelectricity*

Mountains are a great potential source of hydroelectric power. Every large valley with a perennial river can be impounded within the mountain by a dam, and a reservoir created. From the enormous volume as well as velocity of waters, a large amount of hydroelectricity can be produced. Also, the water after generating hydroelectricity flows through canals. Such canals are used for irrigation and for inland navigation. The sources of water in mountainous regions are high rainfall, melting glaciers, melting snow, and springs. The sites of waterfalls are favourable for the generation of hydroelectricity. In many countries of the world, hydroelectricity is now produced so widely and in such large quantities that it has substantially replaced the use of coal. Hydroelectricity is often termed the *white coal*. Hydroelectricity has greatly helped Sweden, Norway, Switzerland, Italy, Japan, Canada, the U.S.A. and the Soviet Union in their economic development.

#### *Mountains and rivers*

Most of the large rivers of the world originate in the mountains. Mountain rivers produce hydroelectricity, deposit

alluvium which serves as the basis for agriculture, and supply water to canals. As a matter of fact, but for the mountains, there would be no vast fertile plains which are features of deposition created by rivers flowing from mountains.

#### *Mountains and tourism*

With the enormous diversity in their landscapes and scenic beauty, health-giving hot water and mineral springs, ice-covered slopes for skiing, and rivers for fishing, mountains attract a large number of tourists. Tourism is now a major industry in some mountainous lands. Countries like Switzerland and Nepal derive a considerable part of their national income from mountain tourism.

#### *Mountains as barriers to transport*

The complex topography of mountains forces isolation on individual valleys. A high mountain range, such as the Himalayas, acts as a barrier in trade and transport between adjoining regions. Construction and maintenance of road is difficult and costly in mountain lands.

#### *Mountains and political boundaries*

Mountains also act as effective political frontiers and boundaries. The boundaries of many countries run along the water-sheds of mountain ridges. Such boundaries were very effective till the dawn of the modern air age. However, such political boundaries continue to have their economic significance even today. Shifting of a mountain political boundary may result in the loss of a part of a river basin and thus deprive a country of the full discharge of water flowing into it. Such boundary changes may also result in international disputes.

#### **Plateaus**

The most important economic contribution of plateaus to human civilisation is their rich store of minerals. Plateaus all over the world, such as the Brazilian, South African, Deccan (India) and West Australian, produce a large variety of minerals. Most of the minerals have their reserves associated with igneous and metamorphic rocks. Coal, iron, copper, gold, diamond, manganese, mica, and several strategic minerals, too, occur in large quantities in the plateaus.

#### **Plains**

Plains, particularly alluvial plains, have been the 'cradles of civilisation'. The Nile, Babylonian, Indus and Chinese civilisations originated and flourished in great alluvial plains. Agriculture, industries, and transport, the three basic factors of civilisation, develop best in the physical environment of the plains.

Plains have a level topography and thick, fertile soils. Laying of agricultural fields, their maintenance, and their irrigation are easy and less costly. Ploughing is effective and needs little labour. Easily, the greatest factor promoting agriculture in plains is the annually renewed deposition of alluvium. This replenishes the soil continually with rich plant nutrients and ensures high crop yields. Agriculture in the Nile Valley of Egypt and in the Ganga basin in India are good examples.

Since transport is easy and agriculture highly developed, plains become densely populated. Demands of the large population then promote a large number of industries. Most of these industries derive their raw materials, directly or indirectly, from the agricultural produce. The raw

materials required by many other industries are derived from agriculture, forestry, and mining. Plains provide facilities for the assembly of raw materials at the sites of factories, through a good transport network and they also facilitate the distribution of finished products over wide areas. A large population of the plains also provides adequate labour and potential market for these industries.

The level topography of the plains facilitates the construction of a close

network of roads. Both the construction and maintenance of roads are economical. Rivers of the plains flow on gentle gradients. They are, therefore, used for inland water transport. River and canal transport costs much less. There is also a large network of railways in the plains. Their construction is both easy and more economical. How plains promote transport networks can be well seen if we see a transport map of the North Indian plains.

### EXERCISES

1. Name the principal resources of mountains which have been exploited and utilized by man.
2. Why do mountains have such a large potential for the production of hydroelectric power?
3. Plateaus are regarded as the storehouses of minerals. Why?
4. Man's occupancy of the plains is the oldest and the most intense. Why?

### Books for further study

Finch, V.C. et. al., *Elements of Geography* New York : Mc Graw-Hill, 1968.  
Huntington, E., *Principles of Human Geography*, Bombay : Asia Publishing House, 1959.



UNIT III

# Climatology



## CHAPTER 11

# Climate and Man

**C**limatology is the study of the genetic processes and the distributional patterns of atmospheric conditions immediately surrounding the earth's surface. It includes the study of both climate and weather of a place, a region, or the entire earth.

### Weather

Weather is the sum total of atmospheric conditions existing at any place at a particular instant of time. These conditions are expressed by a combination of several elements. The primary elements are (i) temperature and (ii) humidity and precipitation. Weather refers to the atmospheric conditions in a place or in an area in terms of these elements for a very short period of time. It can, however, refer to the entire earth or a part of it. This is the reason why the All India

Radio broadcasts the weather conditions, and we have the weather maps published by the Indian Meteorological Department. The science which studies weather is known as *Meteorology*.

### Climate

Climate is an aggregate of the changing daily weather conditions. It refers to longer periods of time. The periods of time may be long, and they may refer to the periods as old as the Pleistocene in geology or the last 500 years of human history or any reasonable recent span of time. Studies of Indian climates, for example are based on the data relating to the last about 100 years. But climate does not refer to a day's or a week's weather conditions. Strictly speaking, climate is not average weather. The deviations from the average are as

important as the averages themselves. Prominent departures are as important as the average. Spatially, climate may refer to the entire earth or a part of it. Mostly, climate deals with the characteristics and distribution of not only the individual weather elements, but also with their combinations. These combinations existing over long periods of time produce the characteristics of climates. In these combinations individual events which had occurred only on few occasions are also taken into account; as, for example, occurrences of heavy rainfall and devastating cyclones.

The basic difference, therefore, between weather and climate is that the former refers to a short and the latter to a much longer period.

There are two methods by which climate can be identified (i) by combining the averages of several climatic elements, particularly temperature and precipitation, and (ii) by arranging and generalising the various types of weather which in combination constitute climate.

#### Climatic elements and controls

The following elements influence the making of climates: temperature, precipitation, humidity, air pressure, and winds.

These climatic elements individually and in combination with each other vary from place to place and from season to season. These variations ultimately produce climatic variations. The variations are produced by an interplay of factors which are termed *climatic controls*. Latitude of location, temperature, land and water contrasts, semipermanent low and high pressure cells, winds, air masses, altitude, mountain barriers, ocean currents,

and storms are the main climatic factors.

Like all other branches of geography, climatology has two basic approaches of study: systematic and regional. Thus, we have systematic and regional climatology. The former deals with the general principles applicable to the entire earth while the latter studies the climates of specific regions. In the former, individual elements are studied for their spatial variations and combinations; in the latter, the elements are integrated in terms of units of space. In the branch of systematic climatology, there are now fields of study such as physical, dynamic, synthetic, historical, agricultural, and urban climatology.

Climate constitutes one of the most fundamental components of the natural environment. It represents the living atmosphere which with hydrosphere, lithosphere, and biosphere constitute the natural environment. Climate affects and is affected by the processes and condition of the other three components of natural environment. A mountain, through its height, affects temperature and rainfall. Rainfall, in its own turn, causes mechanical weathering and erosion. Climate sets limits to the distribution of different kinds of vegetation and animals.

Climate has a great significance in man's life. It has both direct and indirect influence on human activities. Agriculture, irrigation, production of hydroelectricity, forestry, civil engineering, transport, house types, and soil erosion are but a few of the aspects of man's existence on the earth which are related to climatic conditions. Think of the problems of flood, fluctuations of water-table, blowing of hot winds, devastating

cyclones, hazards of snow and ice, fog, will appreciate the innumerable points at and droughts leading to famines, and you which climate affects human activities.

### E X E R C I S E S

1. Define climatology.
2. How would you distinguish climatology from meteorology ?
3. What is the significance of climatology for man ?
4. Explain with examples, the difference between weather and climate.

### Books for further study

- Trewartha, G., *An Introduction to Climate* New York : Mc-Graw-Hill, 1954.  
Critchfield, H., *General Climatology*, New York : Prentice-Hall, 1961.  
Hare; F.K., *The Restless Atmosphere*, London : Hutchinson, 1966.  
Barry, R.G. *Atmosphere, Weather and Climate*, London : Methuen, 1968.



## CHAPTER 12

# Composition and Structure of The Atmosphere

The structure of the atmosphere refers to its layered arrangement. Our knowledge about this layered structure is derived from the known vertical differences in temperature, movement, composition, degree of electrical charging and radio-wave propagation. The structure has been identified on the basis of several observations. The methods of observations include human effort in mountain climbing, gunfire, unmanned balloons, sound probing from ground, searchlight density probes, V-2 rockets, radio probing, present-day rockets equipped with scientific instruments, and artificial satellites. While mountain climbing gives information of up to 8 kms, artificial satellites provide data for up to 400 kms.

The structure of the atmosphere is highly complex, but its layering is now well understood. Temperature changes irregularly with height. There are three parts of the graph which show these changes ; (a) a slow decrease in temperature up to 15 kms, followed by (b) a fairly constant temperature, and then by (c) a rapid rise of temperature above 80 kms. Clouds and humidity are concentrated within the first 15 kms. layer.

### Layers

The structure of the atmosphere consists of five basic layers : the troposphere, the stratosphere, the ionosphere, the exosphere, and the magnetosphere. Of these, the troposphere is the most important in climatology since it is the locale of all the

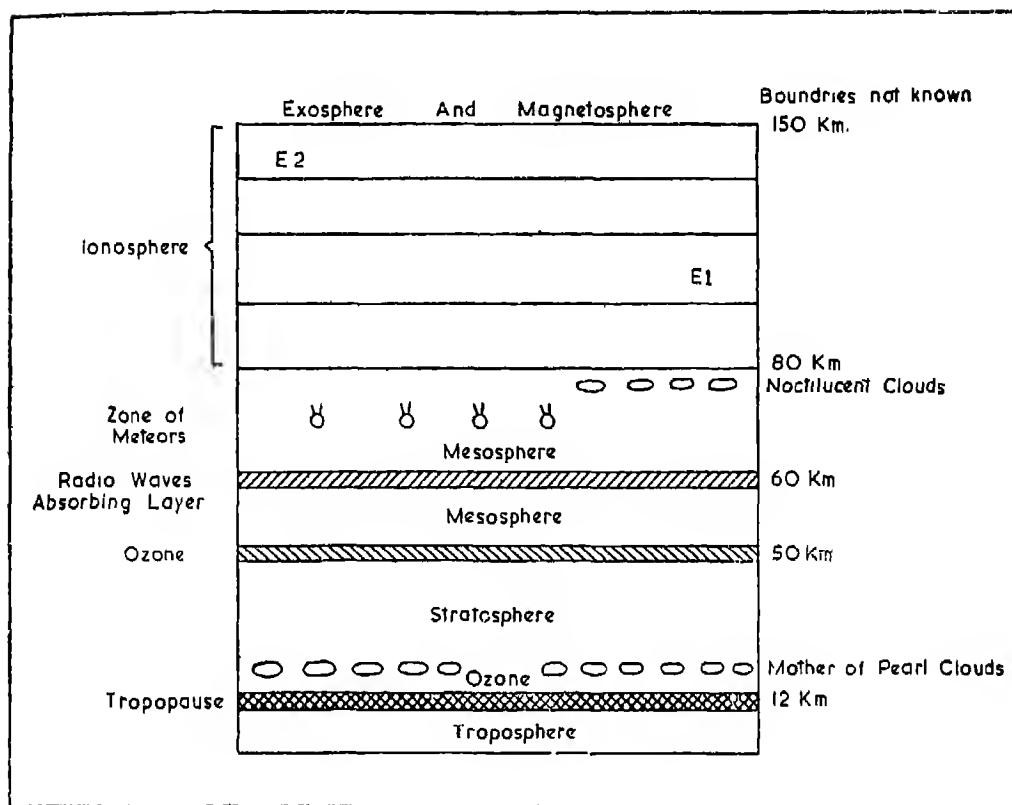


Fig. 56. Layered structure of Atmosphere

vital atmospheric processes which create the climatic and weather conditions on the earth's surface. This layer immediately overlies the earth's surface (Fig. 56).  
**Troposphere**

The average thickness of the troposphere is about 16 kms. It varies from 8 kms. at the North Pole to about 16 to 20 kms. at the Equator (Fig. 57). Near the equator, insolation is high, the surface becomes heated, convectional currents are very strong, and these currents transport the heat to great heights. Thus, at the equator, the thickness of the troposphere

is the greatest. The troposphere at any latitude is thicker in summer than in winter. The transition separating the troposphere from the stratosphere is termed *tropopause*.

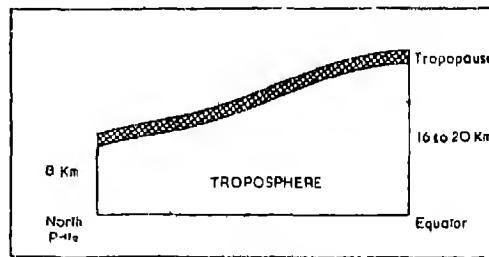


Fig. 57. Troposphere

The temperature of air in the troposphere decreases at the rate of  $1^{\circ}\text{C}$  per 165 metres of height. This is termed as the *normal lapse rate of temperature*. In the lower part of the troposphere, however, the lapse rate along the vertical is very steep.

Innumerable vertical currents moving throughout the year cause the troposphere to remain unstable. Instability leads to upward movement, condensation, formation of clouds, and precipitation.

### **Composition of the Atmosphere**

The atmospheric composition of the troposphere reveals two major constituents : molecular nitrogen and molecular oxygen. The former occupies 78 per cent and the latter 21 per cent by volume. The minor constituents include carbon dioxide, carbon monoxide, methane, nitrogen dioxide, nitrous oxide, water vapour, ozone, and dust particles. Actually, the atmosphere is a mixture of gases. Of the many constituents, the most important for the earth's climatic conditions are water vapour, dust, carbon dioxide, and ozone.

### **Water Vapour**

Water vapour absorbs the insolation coming from the sun and thus reduces the amount of insolation reaching the earth's surface. It preserves the earth's radiated heat. It thus acts like a blanket allowing the earth neither to become too cold nor too hot. Water vapour is the immediate cause of condensation and precipitation. In these two processes water vapour both releases and consumes latent heat of condensation which cools and warms the air. Conditions of stability and instability in the air are greatly influenced by the role of water vapour. The amount of water vapour decreases with altitude, so that

half the water vapour in the air lies below an altitude of about 2000 metres. It also decreases from the equator toward the poles with the maximum occurring between  $10^{\circ}$  and  $30^{\circ}$  latitudes.

### **Dust Particles**

Dust occurs in the form of myriads of tiny particles. They are kept afloat by the slight movements of air. The sources of dust include the dry, desert plains, lake beds and beaches, dry river beds, explosive volcanoes, and meteors. Oceanic salts also constitute dust particles. Dust particles are concentrated in the lower layers, although convectional currents can transport them to great heights. Similarly, the amount of dust is far less in the equatorial and polar regions than in the sub-tropical and temperate dry and windy areas. Dust particles play an important role in the heating of atmosphere by scattering and diffusing insolation. They also serve as hygroscopic nuclei around which water vapour condenses to produce clouds. In general, salt particles form the ideal hygroscopic nuclei. Dense haze and smog (smoke+fog) are developed around dust particles.

### **Other Gases**

Carbon dioxide constitutes only 0.33 per cent of the volume of the atmosphere. Even so, it is extremely important because it absorbs heat coming from both the sun and the earth. Thus, it produces a greenhouse effect.

Ozone absorbs ultra-violet radiations from insolation and thus reduces the amount of insolation. Ozone has its greatest concentration at about 50 kms, altitude in lower latitudes.

Of the inert gases, the most important is argon. By volume it forms about 0.93

per cent of the atmosphere. Other inert gases include neon, helium, krypton, and xenon, all of which have no significance in the weather processes of the earth.

### EXERCISES

1. Name the main constituents of the atmosphere.
2. What is the significance of dust particles in the atmosphere ?
3. Name the main layers of the atmosphere.
4. What are the properties of the troposphere ?
5. Why is the troposphere considered to be the most significant layer of the atmosphere ?
6. Describe the role of water vapour in the weather processes.

### Books for further study

Trewartha, G., *An Introduction to Climate*, New York : McGraw-Hill, 1954.  
Critchfield, H., *General Climatology*, New York : Prentice-Hall, 1961.



## Insolation and Heat Budget

**I**nsolation is the energy radiating from the sun's surface. It moves with the speed of light, that is, 186,000 miles or about 300,000 kms per second. The insolation received by the earth is only  $\frac{1}{1000}$  millionth part of the total energy radiated from the sun's surface. By definition, insolation is the incoming solar radiation ( $\text{in} + \text{sol} + \text{ation}$ ).

Insolation is the most important single source of atmospheric heat. Hence, its distribution over the globe is highly significant in controlling weather and climate.

Two major factors control the amount of insolation received at any portion of the earth's surface : (i) the intensity of solar radiation or the angle of incidence of insolation or the sun's rays, and (ii) the duration of solar radiation or the length of the day. The angle of incidence determines the area of the

earth's surface affected by it and also the loss that it suffers through the thickness of the atmospheric path (Fig. 58). When the angle of incidence is high, the area affected is small. Insolation is concentrated on a smaller area, hence the heat

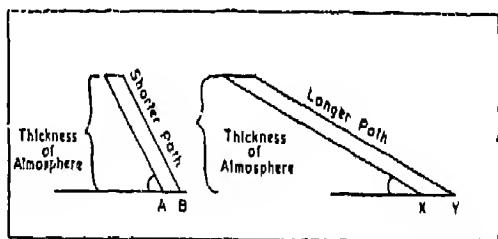


Fig. 58. Angle of incidence of insolation and Area Affected

received per unit area is large and the surface is heated to a higher degree. Also, the high angle of incidence means that the length of the path of the insolation rays through the atmosphere is shorter, and it loses only a small amount of its heat

through absorption, scattering, and reflection. On the other hand, where the angle of incidence is smaller, the area affected is larger and the heat per unit of area is much less. At the same time, the longer path through the atmosphere results in a larger amount of loss of heat. The duration of solar radiation or the length of the day determines the amount of heat received by the earth's surface and also contributes to its temperature. The two features operate jointly and produce complexities of distribution.

Four aspects regarding the amount of insolation produced by this interplay are of interest : (i) the angle of incidence of insolation and the duration of sunlight are directly proportionate to the amount (ii) on the same parallel of latitude, the values of the two controls (*namely the angle of incidence of insolation and the duration of sunlight*) are the same, and hence the amount of insolation on it remains the same, (iii) different parallels receive different amounts of insolation, and (iv) insolation decreases from the equator to the poles for the year as a whole.

### **Horizontal Distribution of Insolation**

The horizontal distribution of insolation can be studied under two heads : (i) along a meridian, and (ii) for selected latitudes.

(i) *From pole to pole along a meridian at the outer limits of atmosphere*

This discussion is conducted for three time periods : annual, equinoxes, and solstices.

(a) *Annual* : The maximum insolation is received at the equator. There is a gradual reduction in a regular manner toward the poles. At the poles, the amount received

is the minimum and is 1/40th of that received at the equator. The annual march is represented by a symmetrical curve. This distribution is very largely the result of the fact that the sun's rays fall on the equatorial region at very high angles and the angle of incidence becomes smaller toward the poles. Also, there is a decrease of the duration of sunlight from the equator toward the pole. Hence, it is found that the equator and the poles receive 350 and 150 thermal days, respectively (one thermal day is equivalent to the average total daily insolation received at the equator.)

(b) *Equinoxes (Spring and Autumn)* : These conditions are obtained in the months of March and September when the sun shines vertically over the equator and tangentially at the poles. The duration of sunlight is equal at all the parallels.

The curve of distribution resembles broadly the curve of annual distribution. The maximum is found at the equator and the minimum at the poles. An important fact is that the values at the poles reach zero. The curve is symmetrical.

There are at least three points of climatic significance in the equinoctial distribution : (i) in spring and autumn the distribution of insolation, temperature, pressure, winds, and precipitation over the earth is similar to that for the year as a whole, (ii) equal amounts of insolation are received by the Northern and Southern Hemispheres, and (iii) similar temperatures occur in the two hemispheres, and other climatic elements are in balance to the north and the south of the equator.

(c) *Solstices (Summer and Winter)* : These conditions are obtained in the

months of June and December. At this time the midday rays of the sun fall vertically on the Tropic of Cancer in June and on the Tropic of Capricorn in December.

At the top of the atmosphere there is unequal distribution of insolation in the two hemispheres. The summer hemisphere receives 2 times the insolation received by the winter hemisphere. Beginning from zero at the Antarctic Circle, the insolation curve rises steadily up to about  $44^{\circ}\text{N}$ . North of this latitude there is a slight decline up to  $62^{\circ}\text{N}$ . This is due to the offsetting of the effects of the increased length of the day by those of more oblique rays. The curve rises north of  $62^{\circ}\text{N}$  and reaches an absolute maximum at the North Pole. The curve of insolation is complicated by the interplay of the

angle of incidence and the duration of insolation. Their maximum effects do not occur along the same latitudes.

At the surface of the earth there is a reduction in the intensity of insolation. This is due to the effects of reflection, scattering, and absorption by the atmosphere. There is a shift in the latitudinal location of the maximum amounts of insolation, so that the poles receive less insolation than the equator. In the summer hemisphere there is uniform distribution of insolation with latitude. There is a broad zone of maximum near lat.  $60^{\circ}\text{N}$ .

There are four climatic effects : (i) The maximum surface temperatures occur on land masses of lower middle latitudes. This coincides with a broad zone of maximum insolation in the same latitudes.

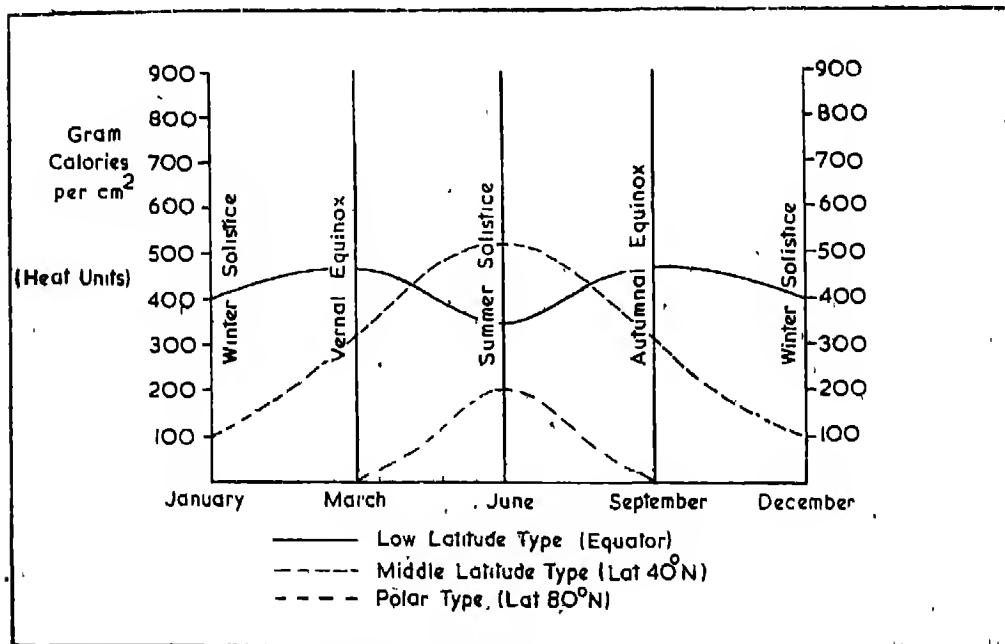


Fig. 59. March of Insolation

(ii) There is a striking latitudinal shift of temperature, pressure, wind, and precipitation from the summer to the winter hemisphere. This follows a similar migration of insolation. (iii) The latitudinal temperature gradient is much steeper in the winter than in the summer hemisphere. (iv) Storminess and variability of weather are much greater in the winter than in the summer hemisphere. This is related to the steeper temperature gradient in the former.

(ii) *Annual Distribution of Solar Radiation for Selected Latitudes on the Earth's Surface.*

*Low Latitude Tropical Type :* About 400 units are received in December and a little less in June. These small values are related to the apparent

movement of the sun away from the equator where the rays fall obliquely. In March and September, about 500 units are received.

Thus, the range of insolation between the solstice and the equinox is about 100 units. There is little seasonal variation and the values are constantly high. The most striking characteristic is the presence of two maxima and two minima, both related to apparent movement of the sun across the equator (Fig. 59).

*Middle Latitude Type :* The lowest values of about 100 units of heat occur in January and December and the highest of about 500 units occur in June. The seasonal ranges between the two solstices and the equinox are 400 to 200 units, respectively. Since insolation is never absent, the values never reach zero.

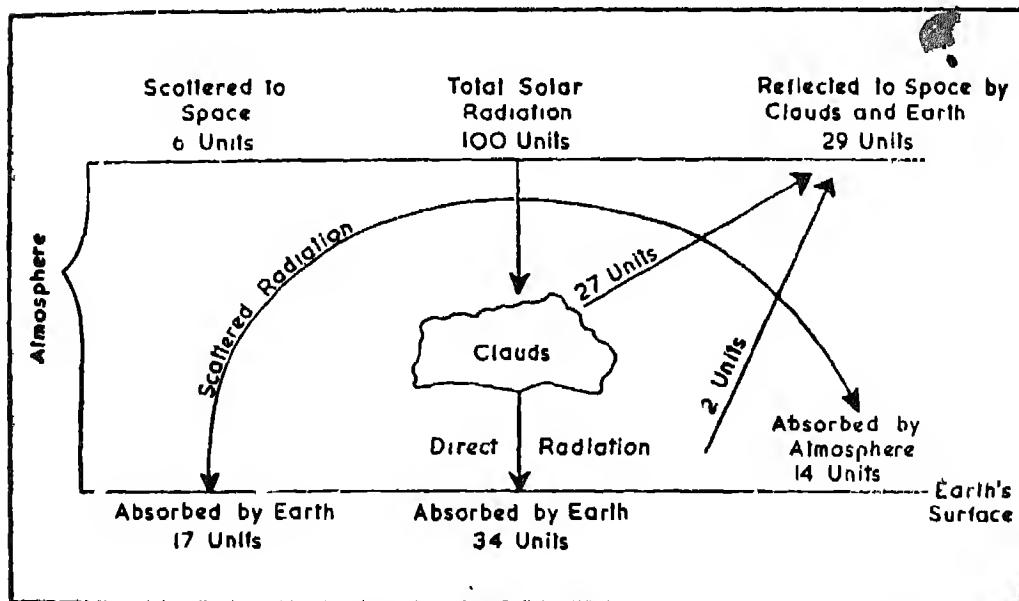


Fig. 60. Heat Budget

The greater seasonal extremes of insolation result in greater seasonal extremes of temperatures. There is one maximum and one minimum.

*Polar Type*: The values are zero in March and September, above zero between March and September, and above zero between September and March. The maximum heat of 300 units is received in June. The seasonal ranges between the solstices and between one solstice and the succeeding equinox are 300 units. There is one maximum and one minimum.

The atmosphere is heated by conduction, convection, radiation and advection. *Conduction* is the process in which heat

flows from a region of higher temperature to a region of lower temperature. In this process, the molecules in a medium do not move but transfer the heat to the adjacent molecules. Air, being a gas, has very low conductivity, hence the process of conduction has little significance in the heating and cooling of the atmosphere. In *convection*, there is an actual motion of a part of the medium or molecules and, thus, heat is transferred from a hotter to a colder region. Convection is the most important heating process in atmosphere. *Radiation* is a transfer of heat through a medium without affecting it. The medium is not heated. The radiation coming from

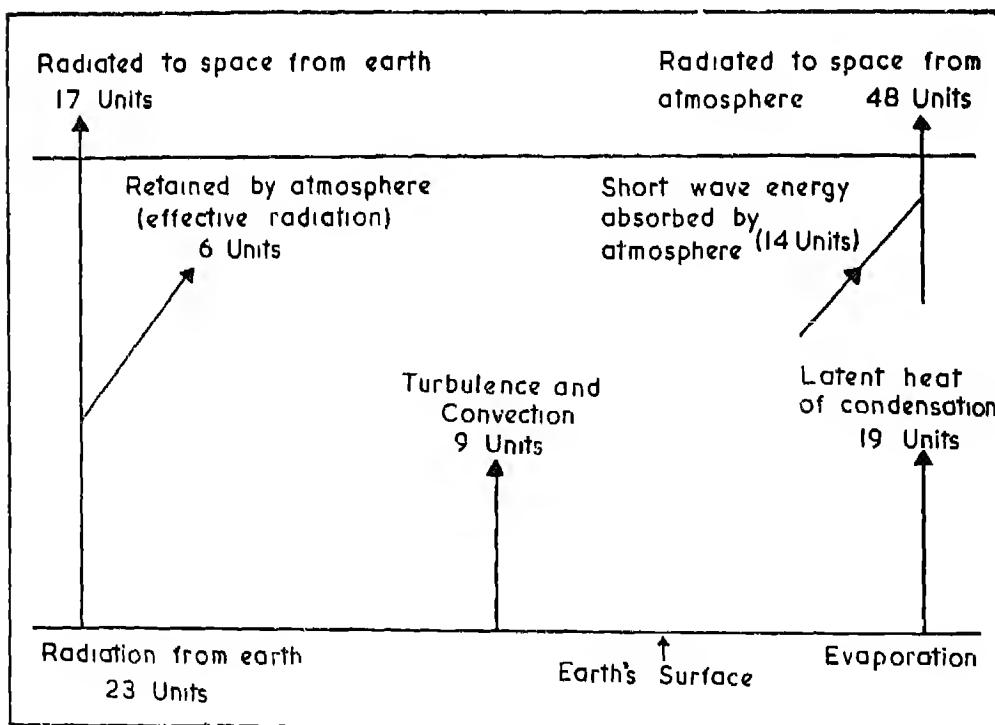


Fig. 61. Terrestrial Radiation

the sun does not heat the atmosphere which is heated by ground or terrestrial radiation. *Ground radiation* comprises long-range wave energy rays and these heat the atmosphere. In *advection*, there is a horizontal movement of air masses which transfer heat from a hotter to a colder region. Also, a cold air mass moving into a warmer region reduces its temperature. While convection results in the vertical transfer, advection results in the horizontal transfer of heat.

### **Heat Budget**

It has been found that the yearly mean temperature of the earth remains constant. The incoming short-wave solar radiation is balanced by an equal amount of long-wave earth radiation going back to space. This is termed *heat balance* or *heat budget* of the earth.

Let us assume that the total heat received at the top of the atmosphere is 100 units. Fig. 60 shows that the atmosphere absorbs directly 14 units of this heat and the earth receives 51 units, totalling 65 units. The remaining heat of 35 units is lost to the space, owing to the reflection from the top of the atmosphere (6 units), from the top of the clouds (27 units), and from the snow and ice-covered areas of the earth's surface (24 units). This total reflection is called the *albedo of the earth*. The 65 units received by the earth gradually escape back into the space in the form of terrestrial radiation. From Fig. 60 it can be seen that the total radiation returning from the earth and atmosphere to space is  $48 + 17 = 65$  units which balance the total of 65 units received from the sun. This is termed the *heat balance of the earth* (Fig. 61).

## **E X E R C I S E S**

1. Define insolation.
2. What are the units of the wave lengths of insolation ?
3. Name the two major factors which control the amount of insolation.
4. Why do different parallels receive different amounts of insolation ?
5. What are the salient features of distribution of insolation along a meridian ?
6. Explain the concept of heat budget.

### **Books for further study**

- Trewartha, G., *An Introduction to Climate*, New York : McGraw-Hill, 1954.  
 Critchfield, H., *General Climatology*, New York : Prentice-Hall, 1961.  
 Barry, R.J., *Atmosphere, Weather and Climate*, London : Methuen, 1968.



## Distribution of Temperature

**B**y horizontal distribution we mean the distribution of temperature across latitudes. Temperature changes slowly across latitudes.

### Horizontal Distribution

The horizontal distribution of temperature is shown by isothermal maps. An isotherm is a line joining places having equal temperatures. In drawing an isotherm, the temperatures are reduced to sea-level to eliminate the effects of altitude. Suppose there are two places X and Y having the July temperatures of  $32^{\circ}\text{C}$  and  $25^{\circ}\text{C}$  and located at sea-level and at an altitude of 1300 metres, respectively. Then, the temperature of Y reduced to sea-level would be about  $14^{\circ}\text{C}$ .

Three general characteristics of isotherms are to be noted : (i) isotherms trend east-west, generally following the parallels,

(ii) because of land-water contrasts, isotherms take sudden bends at land-water edges, and (iii) the spacing of isotherms indicates the latitudinal thermal gradient.

The close correspondence between the isotherms and the parallels of latitudes is very largely due to the same amount of insolation received by all the points located on the same latitude. During summer an isotherm bends toward the equator on the ocean at the ocean-land edge. As Fig. 62-A shows, along the  $30^{\circ}$  latitude parallel land is warmer than ocean and the same temperature of  $16^{\circ}\text{C}$  will occur toward the equator. Hence, the equatorward bending. In contrast, during winter, the land is cooler than the ocean, and equally low temperature on the ocean will occur away from the equator. Hence,

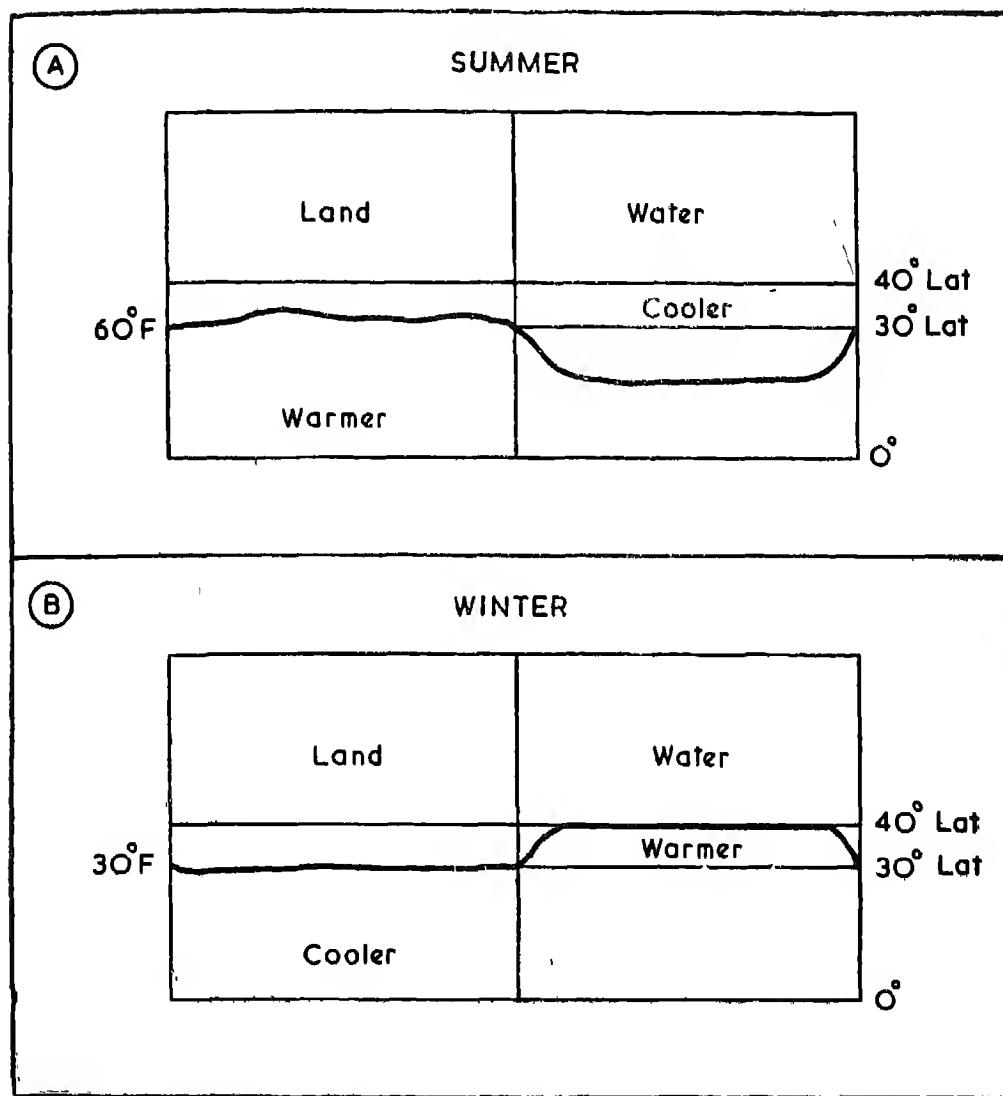


Fig. 62. Distribution of Temperature of land and water in summer and winter

the poleward bending (Fig. 62-B). And lastly, the close spacing of the isotherms indicates a rapid change in the temperature over the latitudinal parallels, and the wide spacing is a measure of the slow change.

#### *Features of Distribution*

These can be systematically studied for three time periods : annual, January and July.

*Annual* : The highest and the lowest values occur in the low latitudes and at

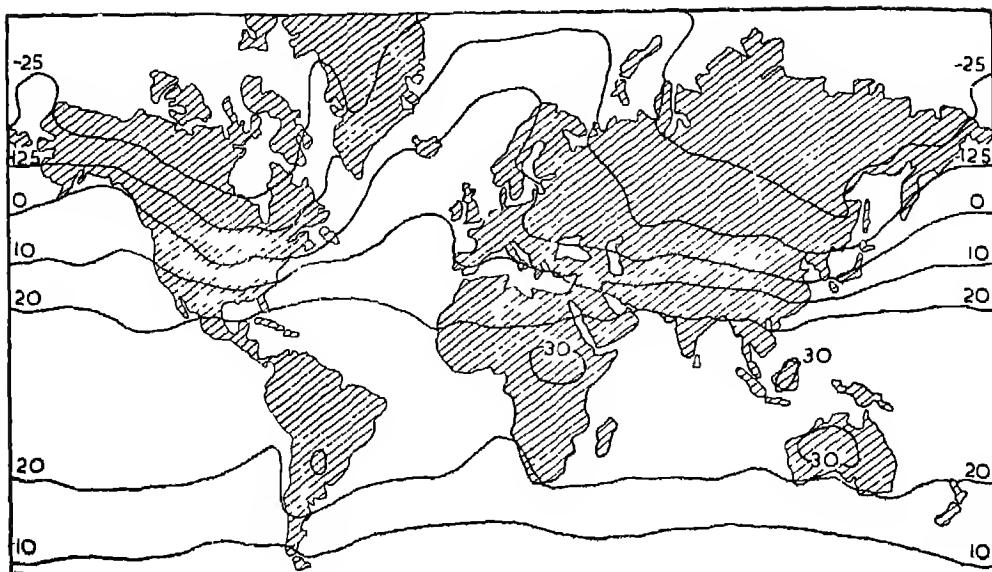


Fig. 63. January Isotherms

the poles, respectively. This is related primarily to a regular decrease of insolation from the equator to the poles. Within the tropics, a low-latitude zone of  $23\frac{1}{2}^{\circ}$  on either side of the equator, there is no marked north-south temperature gradient.

Isotherms are straighter and widely spaced in the Southern Hemisphere than in the Northern Hemisphere. This is because the Southern Hemisphere has a broad expanse of oceanic waters and in the Northern there is a great contrast between the oceans and the continents. At land-water edges, isotherms reveal bends which are related to land-water contrasts and to cool and warm ocean currents.

*January.* At this time, the highest temperature occurs on land areas. The temperature of more than  $30^{\circ}\text{C}$  occurs in four areas of the Southern Hemisphere : North-west Argentina, East-central Africa, Borneo, and Central

Australia. The first and the fourth are located near the Tropic of Capricorn, while the other two are located near the equator. In general, the higher temperatures occur in the Southern Hemisphere and the lower in the Northern. The lowest temperature occurs in north-east Asia. In the Southern Hemisphere, the temperature nowhere falls below zero (Fig. 63).

Isotherms bend poleward on the oceans and equator-ward on the continents in the Northern Hemisphere. They bend toward the equator on the oceans and poleward on the continents in the Southern Hemisphere. Isotherms are irregular in the Northern Hemisphere and more regular and trending east-west in the Southern Hemisphere. Also, isotherms are characterised by closer spacing in the Northern and wider spacing in the Southern Hemisphere. Hence, the latitu-

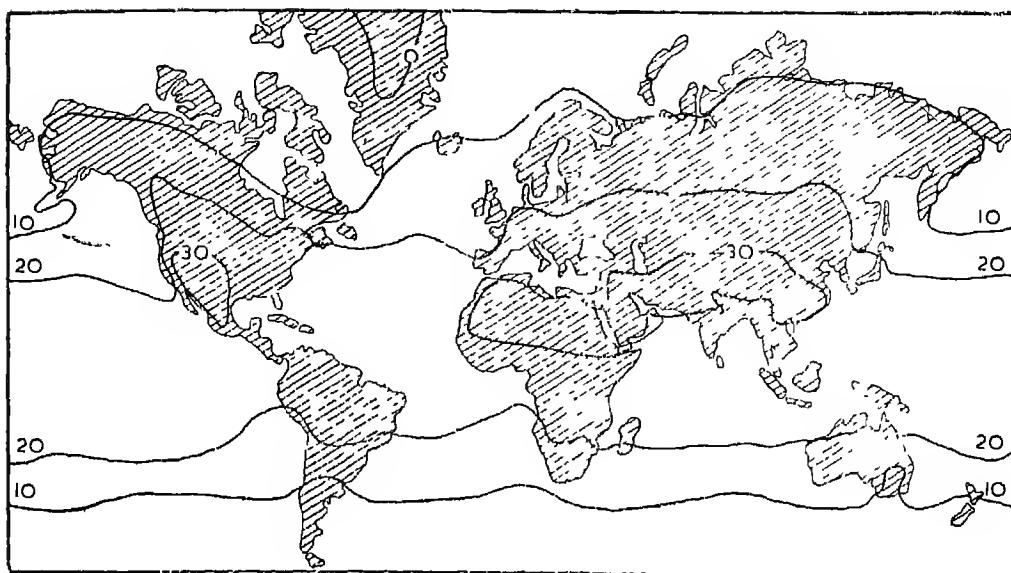


Fig. 64. July Isotherms

dinal temperature gradients are steeper now than during the summer.

*July*: At this time, the maximum temperature of above 30°C occurs entirely in the Northern Hemisphere between 10° and 40°N latitudes. The areas included are the south-western U.S.A., the Sahara, Arabia, Iraq, Iran, Afghanistan, the Gobi Desert, large parts of China, and the area surrounding Madras in India. The minimum temperature occurs in the Northern Hemisphere, and in the central parts of Greenland the temperature is below zero (Fig. 64).

Isotherms bend equatorward while crossing the oceans, and poleward while crossing the land masses. Isotherms reveal the wider spacing on the oceans than on the continents. Hence, the temperature gradients are gentler in summer than in winter. Also, isotherms are more regular in the Southern than in

the Northern Hemisphere.

#### Comparison of two solstice conditions

There is a marked latitudinal shifting of isotherms following the apparent movement of the sun. This shifting is much larger on the continents than on the oceans. The highest temperature in January and July occurs on land areas which is ultimately due to the low specific heat of land and the high specific heat of water.

The seasonal contrasts in temperatures are much more pronounced in the Northern than in the Southern Hemisphere. This is, again, related to the extent of the land and water contrasts.

In the Northern Hemisphere, isotherms bend equatorward in January and poleward in July on the continents. But on the oceans, they bend poleward in January and equatorward in July. These bendings are also related to the land and water

contrasts with reference to heating and cooling and ultimately to the differences in their specific heat.

### **Annual Ranges of Temperature**

Annual range is defined as the difference between the average temperature of the warmest and of the coldest month.

Large annual ranges occur characteristically in the Northern Hemisphere, on the continents in middle and higher latitudes. The large range of over  $38^{\circ}\text{C}$  occurs near Verkhoyansk.

Smaller ranges occur in the Southern Hemisphere, near the equator, and over large water bodies.

### **Temperature Anomaly**

The temperature anomaly or *thermal anomaly* is defined as the difference between the mean temperature of any place and the mean temperature of its parallel. It expresses the deviation from the normal. The deviation is caused by the land and water contrasts, ocean currents, and prevalent winds. The distribution of anomalies is studied on the maps showing *is anomals* which are lines joining the places of equal thermal anomalies.

The largest anomalies occur in the Northern and the smallest in the Southern Hemisphere.

For the year as a whole the anomalies are negative, i.e., the temperatures are less than the mean temperature of the latitude on the continents poleward from about  $40^{\circ}$  latitude, and positive, i.e., the temperatures are more than the mean temperature of the parallel, toward the equator. On the oceans, the anomalies are positive poleward from about  $40^{\circ}$  latitude, and negative toward the equator.

During January, the anomalies are positive over the oceans, and negative over the continents. The largest positive anomalies occur along the eastern sides of the mid-latitude oceans and adjacent western margins of the continents. This is caused by the warm Gulf Stream in the Atlantic and the Kuroshio currents in the northern Pacific. The largest positive anomaly occurs in north-western Europe, while the largest negative anomaly occurs in north-western Siberia.

During July, the continents have positive and the oceans have negative anomalies. The largest positive anomalies of more than  $8^{\circ}\text{C}$  occur in tropical and subtropical deserts, south-east U.S.A., the Sahara, Arabia, and Gobi. The largest negative anomalies occur in north-east Atlantic, along the west African coast, coasts of Ecuador, Peru, Colombia, and West South Africa. These are associated with such cold currents as of California, Peru, Labrador, Azores, and Benguela.

### **Vertical Distribution**

The most characteristic feature of the vertical distribution of temperature is its decrease with increasing elevation. This is due to the fact that the atmosphere is heated directly by the heat radiated from the earth's surface. The atmospheric layer immediately overlying the earth's surface receives the maximum heat and hence, its temperature is the highest. The increasingly higher layers receive a lesser amount of heat and, hence, their temperatures become lower. The rate at which the temperature decreases with altitude is  $1^{\circ}\text{C}$  per 165 metres. This is termed the *normal lapse rate*.

Lapse rates can be normal, very steep, or gentle. These variations are caused by the

time of the day, the season, and the location of the place. The lapse rate is steeper during the night, in the winter and in continental locations. It is gentler in the day, and in the summer. To quote the rule, the smaller the angle between the X-axis and the temperature-altitude line, the steeper is the vertical temperature gradient. A horizontal temperature-altitude line indicates the steepest possible gradient. A vertical line suggests the gentlest possible gradient and an isothermal condition.

### Inversion of Temperature

The inversion of temperature is the phenomenon in which there is an increase of temperature with altitude, locally and temporarily. In this condition, obviously, the colder air is located near the earth's surface and the warmer air high above.

Surface inversion occurs in the lower layers of the atmosphere. During the night, cooling is more rapid on the ground than in the air layer immediately overlying it. The degree of the specific heat of the land being small, it soon gets heated and cooled to a great extent. Soon, the air layers above the ground also get cooled and to a greater degree than the higher layers. Hence, the temperature, instead of decreasing, increases with the increasing altitude. The second process producing surface inversion is termed *dynamic inversion*. In this process, there is an advection of cold air masses in the

lower altitudes. This results in the lowering of the temperature of the air layers near the ground.

There are six favourable conditions producing surface inversion : long nights, clear skies or high clouds relatively dry air, slight air movement, snow covered surface, and flattish surfaces with a few topographic depressions. These conditions promote a high rate and a large amount of back radiation from the earth's surface.

Surface inversion has climatic significance. The marked stability of air suppresses convection and turbulent mixing and produces characteristic dryness of air in the upper layers. There is a dense smoke fog (smog) beneath the inversion layer. Since the temperature in the inversion layer is low and the relative humidity is high, fogs form frequently. Stratus clouds are formed below the inversion layer. The dynamic inversion is much more extensive than the local, radiation inversion. Surface inversion is also associated with the air-drainage in the valleys and frosts.

Surface inversion occurs over the polar area, during nights of colder months, over snow-covered land-masses of higher middle latitudes, on the oceans during the day, and in the form of dynamic inversion over the northern lowlands of Eurasia and North America in cooler seasons.

### EXERCISES

1. What is meant by the horizontal distribution of temperature ?
2. What factors control the horizontal distribution of temperature ?

3. Explain the fall of temperature with the increasing altitude.
4. Discuss the inversion of temperature. What are its climatic implications?
5. Why are isotherms generally parallel to the parallels of latitudes?
6. Describe the salient features of the January and July distribution of temperatures.

#### Books for further study

- Trewartha, G., *An Introduction to Climate*, New York : McGraw-Hill, 1954.  
Critchfield, H., *General Climatology*, New York : Prentice-Hall, 1961.  
Strahler, A.N., *Physical Geography*, New York : John Willy, 1960.



## CHAPTER 15

# Pressure and Winds

The atmospheric pressure and winds are significant more as climatic controls and less as climatic elements. Contrasts in temperature cause changes in pressure which generate winds. Winds cause precipitation and affect both temperature and humidity. At the same time, distinctive pressure and wind conditions are characteristic of different climatic types and regions. For example, the Kerala region of India has monsoon climate dominated by monsoon winds and the West European climatic region experiences the westerlies. The equatorial belt has lower air pressure than the subtropical belt of anticyclones.

### Measurement of Air Pressure

The weight of a column of air having a cross-sectional area of one square inch and extending from sea-level to the top

of the atmosphere is 14 lbs. The weight of a mercury column 760 mm tall and one square inch in cross-section is also 14 lbs. This value, 29 inches or 760 mm, is the normal value of the atmospheric pressure at sea-level at 45° latitude. The common measure is *millibar*. One millibar is a force equal to 1,000 dynes per sq. cm., and one dyne is equal to the weight of one milligram. Therefore, one millibar is equal to the force of one gram per sq. cm. Also, one inch of mercury is equivalent to 34 millibars.

### Causes<sup>†</sup> of Pressure Changes and Differences

There are two types of pressure systems : (i) high pressure, and (ii) low pressure. More commonly, high pressure is also known as an *anticyclone* and a *high*. When it has an elongated oval shape, it

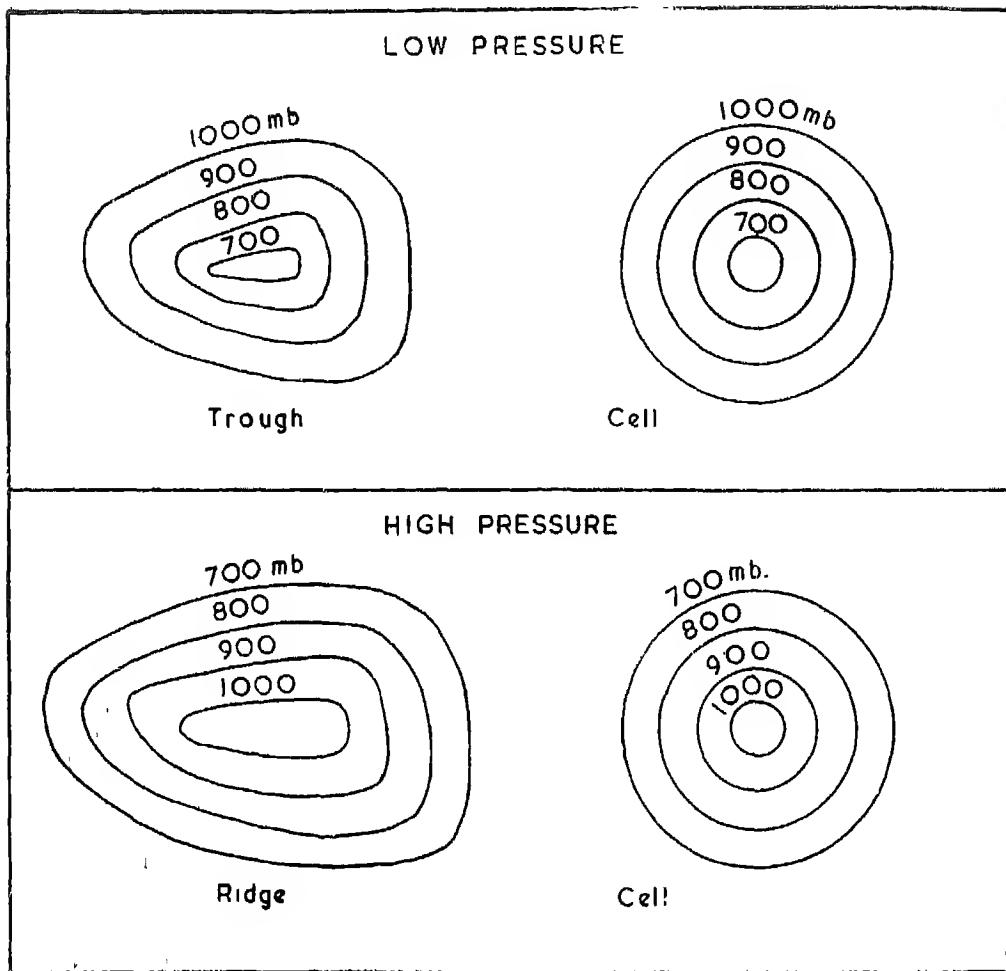


Fig. 65. Low Pressure and High Pressure

is termed *ridge* or *wedge*. Low pressure is also termed a *depression*, a *cyclone*, or a *low*. When elongated, it is known as *trough* (Fig. 65).

There are two causes of the formation of high and low pressure: (i) thermal, and (ii) dynamic. The chain in thermal causation runs like this: heating causes expansion, expansion results in decreasing

the density and this leads to low pressure. In contrast, cooling results in contraction. This increases the density, which results in high pressure.

Three main processes in the formation of thermal *highs* and *lows* can be identified. They are: (i) conduction and radiation, (ii) horizontal advection of warm and cold air masses, and (iii) latent heat

of condensation.

Examples of thermal lows are the equatorial lows occurring during the summer in North America and North India, and those of thermal highs are the polar highs which occur during the winter in North Asia and North America.

The dynamic factor producing high and low atmospheric pressures operates through a frictional *drag* and centrifugal force. Along the equator the velocity of rotation is very high; hence, the centrifugal force (force which throws things out) is very strong. As a result the air mass tends to be thrown out which results in low pressure. Sub-tropical highs and sub-polar lows are examples of dynamically induced pressure systems.

#### Distribution of Atmospheric Pressure

The distribution of atmospheric pressure can be studied in two aspects : (i) vertical, and (ii) horizontal. Climatically, both are important.

##### Vertical Distribution

Atmospheric pressure decreases by 34 mb (millibars) for every about 300 metres of height. This decrease is related to the compressibility of air. The lowest layer is the most highly compressed and, hence, has the highest density and pressure. In contrast, the higher layers are less compressed and, hence, have low density and low pressure.

##### Horizontal Distribution

The distribution of atmospheric pressure across the latitudes is termed *horizontal distribution*. This distribution is expressed by *isobars*. An isobar is an imaginary line drawn through places which have equal atmospheric pressure reduced to sea-level. The spacing of isobars expresses the rate

and direction of the pressure change and the pressure gradient or the barometric slope. Close spacing of isobars indicates a strong gradient, while wide spacing suggests a weak gradient. The *pressure gradient* is defined as the decrease in pressure per unit distance in the direction in which the pressure decreases most rapidly.

The main feature of the distribution of pressure is its zonal or belted character. Each zone or belt comprises several cells of high or low pressures. The cells can be either circular or elongated. The zonal or belted character is strikingly developed in the Southern Hemisphere which has a more homogeneous, water-covered surface. In the Northern Hemisphere, the land-water contrasts, frictional effects, and mountain barriers produce a series of cells aligned with latitudes.

The horizontal distribution of pressure can be studied, in terms of time, under three heads : annual, January, and July.

##### Annual Conditions

The high pressure cells or belts are located at about 30°N and S. These dynamically induced highs are termed *sub-tropical highs*. In the polar areas are located shallow, thermal highs.

There is one low, the Equatorial Trough which is mainly thermal and partly dynamic in origin. The two troughs and individual cells of low pressure are located in the sub-polar latitudes. In the Northern Hemisphere, the cells predominate while a continuous, deep, circum-polar trough of low pressure distinguishes the Southern Hemisphere.

##### January Conditions

The equatorial low-pressure trough shifts a little south of its mean equatorial position. This is due to the southward

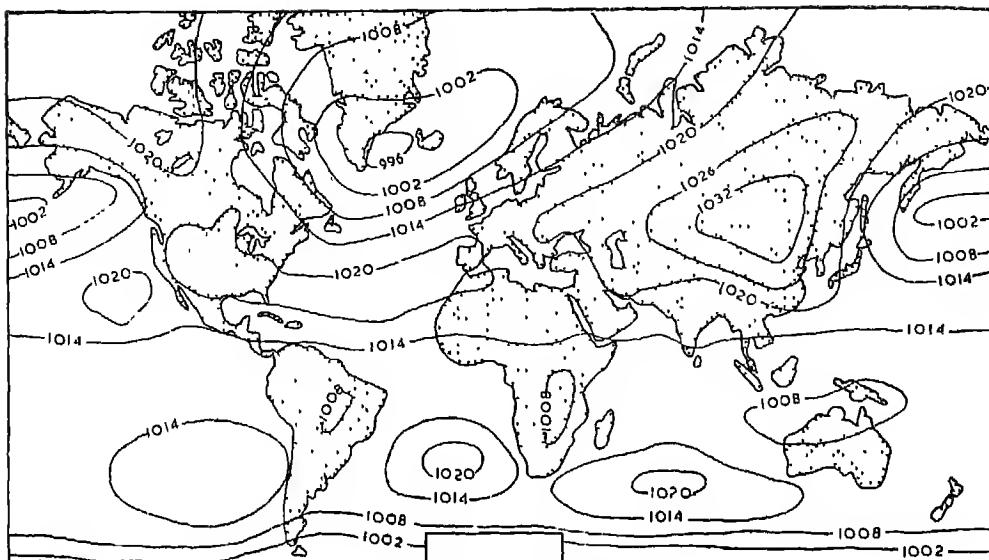


Fig. 66. January Isobars

latitudinal shift of the sun. The lowest pressure pockets in this trough occur in South America, South Africa, and Australia (Fig. 66).

The cells of sub-tropical high pressure are very striking over the oceans in the Southern Hemisphere. They have their maximum development in the eastern parts of the oceans, such as California, Azores, Peru, and Benguela, where the cool ocean currents are effective. In the Northern Hemisphere, the ridges of high pressure occur in the sub-tropical latitudes over the continents. An extensive and well-developed high-pressure cell occurs over East-central Eurasia.

Finally, there is a deep, continuous sub-polar trough in the Southern Hemisphere. In the Northern Hemisphere, there occurs two individual cells of low pressure over North Atlantic and North Pacific, the former is known as the Icelandic low,

and the latter the Aleutian low.

#### July Conditions

The equatorial trough has shifted a little north of the equator following the northward apparent movement of the sun. Thus, all the pressure systems move north during July and south during January in the Northern Hemisphere (Fig. 67).

The sub-tropical belt of high pressure is continuous in the Southern Hemisphere. A high-pressure cell is located over Australia and a few strong cells of high pressure occur over sub-tropical North Atlantic and North Pacific oceans. These extend into the eastern part of the middle-latitude oceans.

There is a deep and continuous trough in the Southern Hemisphere, while in the Northern Hemisphere there is only a faint, oceanic low.

Finally, there are several thermal lows developed over Asia and South-west

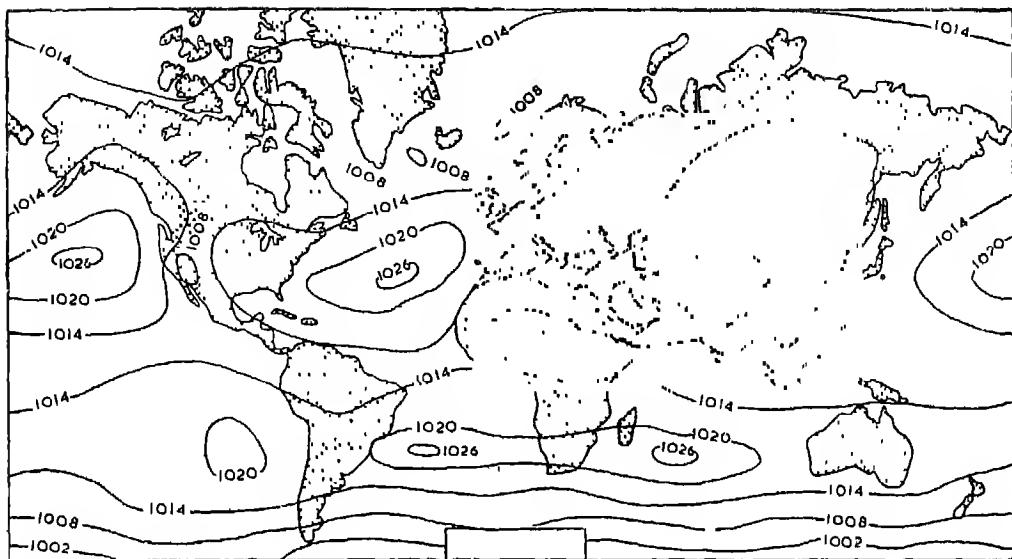


Fig. 67. July Isobars

U.S.A. These lows interrupt the formation of belts.

#### Pressure Belts

On the earth's surface there are in all seven pressure belts. The polar highs, the sub-tropical highs, and the sub-polar lows form matching pairs in the Northern and Southern Hemispheres. The three belts of the Northern Hemisphere are separated from those of the Southern Hemisphere by the equatorial belt (Fig. 68).

The sub-tropical high belts extend from near the tropics to about  $35^{\circ}$ N and S. The sub-polar low belts are located between about  $45^{\circ}$ N and S to about Arctic and Antarctic Circles. The polar high belts are very small in extent and extend around the poles.

The equatorial belt of lows extends from the equator to about  $5^{\circ}$  to  $10^{\circ}$  N and S.

The location of the belts just described is based on the annual averages. Follow-

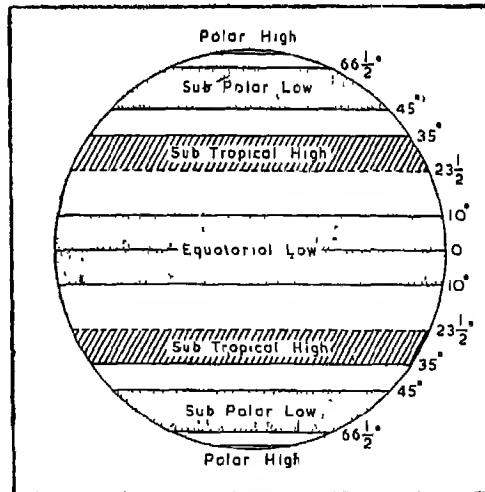


Fig. 68. Pressure Belts

ing the apparent movements of the sun from one to the other hemisphere, the belts also shift their location. This is because of the direct relationship between insolation, heating, expansion, density,

and pressure of air. In the Northern Hemisphere, all the belts shift a little north of their annual average location during the summer and a little south of their location during the winter. Opposite conditions prevail in the Southern Hemisphere.

The belts comprise cells in the Northern Hemisphere and isobaric bands in the Southern Hemisphere. In the belts of high pressure, the air is subsiding and diverging and, hence, stable and dry. On the other hand, the air is converging in the belts of low pressure. Air bodies of different properties clash with each other, rise up, become unstable and cause rainfall. Thus, the high-pressure belts are dry and the low-pressure belts are humid. In both the belts, the winds are light and blow in all the directions.

#### Relation of the Winds Pressure

The main result of the horizontal differences in pressure is the generation of the winds. The horizontal differences in the air density lead to the horizontal differences in the air pressure. This generates the winds. The winds blow from the high-pressure to the low-pressure areas (Fig. 69).

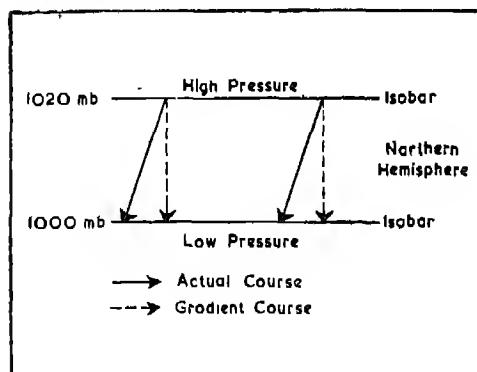


Fig. 69. Relation of Winds to Pressure

#### Pressure Gradient

The rate at which the horizontal pressure changes is indicated by the pressure gradient. The pressure gradient is always at right angles to the isobars. The pressure gradient has two attributes : direction and magnitude. The rate of air-flow or the velocity of the wind is indicated by the steepness of the pressure gradient. Steepness and velocity are directly proportional to each other (Fig. 69).

#### Ferrell's Law

According to this law, the winds turn toward *their* right in the Northern Hemisphere and to *their* left in the Southern Hemisphere. The winds are deflected from their true gradient course as a result of the *coriolis force* which is generated by the rotation of the earth (Fig. 69).

#### Planetary Winds

The planetary winds are permanent winds which blow throughout the year from one latitude to the other in response to the latitudinal differences in air pressure. They blow over the vast areas of the continents and oceans. The two most well-understood and most significant winds for climate and human activities are the trade winds and the westerly winds (Fig. 70).

#### The Trades

The trades are also termed *tropical easterlies* because in both hemispheres they blow from the east to the west from  $30^{\circ}\text{N}$  and  $30^{\circ}\text{S}$  toward the equator. At the  $30^{\circ}\text{N}$  and  $30^{\circ}\text{S}$  latitudes are located the high-pressure cells from where the winds blow toward the equatorial troughs of low pressure. In theory the winds would blow from the north to the south in the Northern Hemisphere and from the south to the north in the Southern Hemisphere,

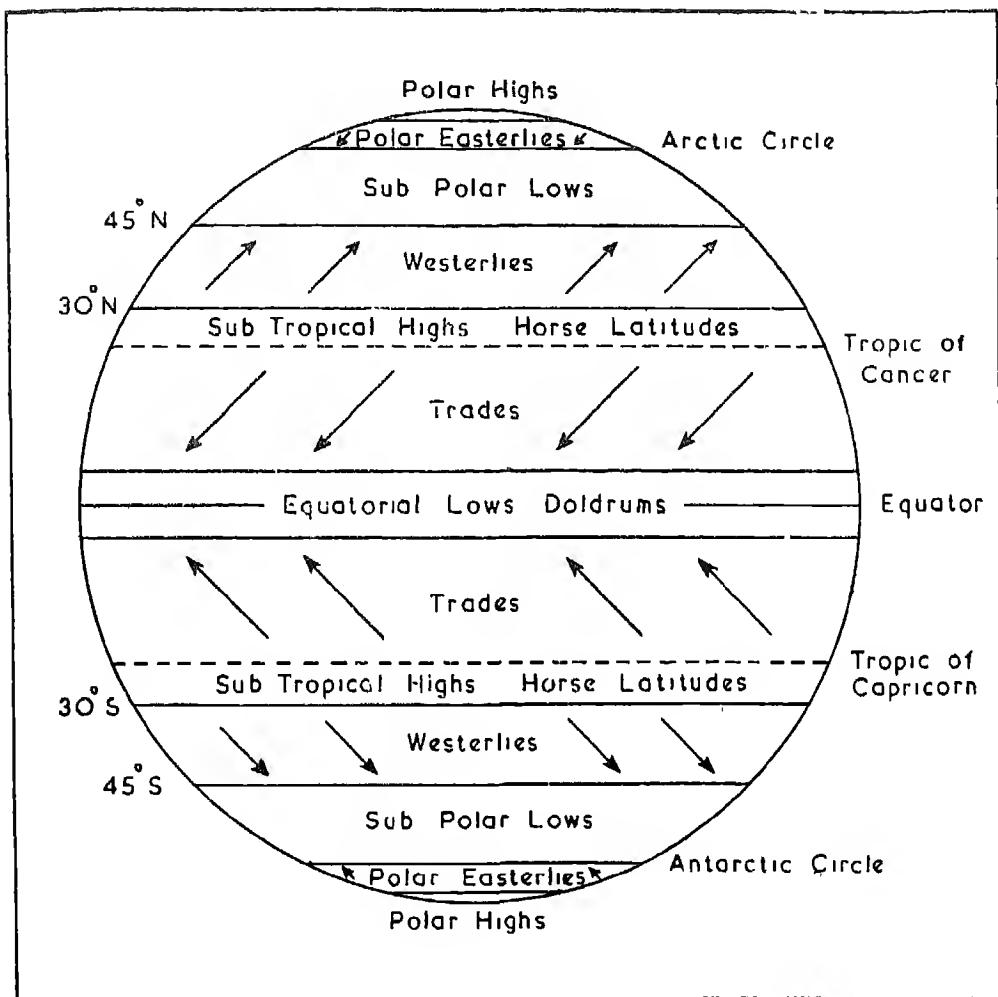


Fig. 70. Planetary Winds

but the coriolis force and the Ferrell's Law explain that the winds turn toward the right in the Northern Hemisphere and to their left in the Southern Hemisphere. Thus, the north-eastern trades in the Northern Hemisphere and the south-eastern trades in the South Hemisphere are produced.

The trades are not one homogeneous

mass. They have contrasting properties in different parts. In their areas of origin, they are descending and stable. Hence, the poleward parts are dry. On the other hand, as the trades approach the equator, they become more humid and warmer and their instability produces copious rainfall. Near the equator, the two trades clash with each other and along the line of

convergence they rise up to produce heavy rainfall. Also, the eastern parts of the trades, associated with cool currents, are drier than the western parts. The trades are steady in the eastern parts and variable in the western parts of the oceans. Also, toward the poles and the equator the trades are highly variable.

### The Westerlies

The westerlies blow from  $35^{\circ}$ - $40^{\circ}$  to  $60^{\circ}$ - $65^{\circ}$ N and S latitudes. They originate in the northern parts of the sub-tropical high-pressure cells, also termed *the horse latitudes*, and blow toward the poles. Their prevailing directions are southwest-northeast and northwest-southeast in the Northern and Southern Hemispheres, respectively. The poleward boundary of the westerlies is highly fluctuating, and there are many seasonal and short-period fluctuations. The westerlies carry many *west-to-east-moving* temperate cyclones embedded in them. They produce spells and variabilities in weather. Stormy winds are more common than the weaker ones. The velocity ranges between 45 and 75 kms per hour and the calms are very rare. The westerlies are best developed between  $40^{\circ}$  and  $65^{\circ}$ S latitudes. *Roaring forties*, *furious fifties*, and *shrieking sixties* are dreaded terms for navigators. The polar parts are more unstable than the sub-tropical margins.

### Monsoon Winds

The word monsoon is derived from the Arabic word *mausim* which means season. Monsoon winds are seasonal winds. The term was first applied to the monsoon winds blowing over the Arabian sea.

In earlier times, it was thought that the monsoon winds were land and sea breezes on a large scale. Thus, the monsoons

were considered convectional circulations on a giant scale.

Among the current theories of origin of the monsoon, the one proposed by Flohn has the widest acceptance (Fig. 71). According to Flohn, the monsoon is a modification of the general planetary wind system. It is superimposed on the general planetary wind system and is not merely convectional. The monsoon is a southwesterly wind and is the northward extension of the equatorial lows. It corresponds to the equatorial winds which, according to Flohn, are westerly. During the summer, the tropical high-pressure belt is displaced northward. The equatorial westerlies embedded in tropical easterlies also move northward. From the ocean, they move toward and blow on the continents. These are the southwesterly, summer monsoons. During the winter, the tropical high-pressure belt and the heat equator retreat southward. The normal trade wind is re-established. This is the winter monsoon.

The monsoon winds blow in India, Pakistan, Bangladesh, Burma, Sri Lanka, Arabian Sea, Bay of Bengal, South-eastern Asia, Northern Australia, China, Japan and South-eastern North America.

The summer monsoon is principally characterised by heavy rainfall that it causes. The winds experience three types of rises Orographic, upward convection, and cyclonic; and with these are related widespread linear rainfall, rainfall concentrated at a few localities, and rainfall scattered over large areas, respectively. The weather associated with the summer monsoon is highly variable and characterised by frequent spells of drought and rainy days. In the lowlands, rain is

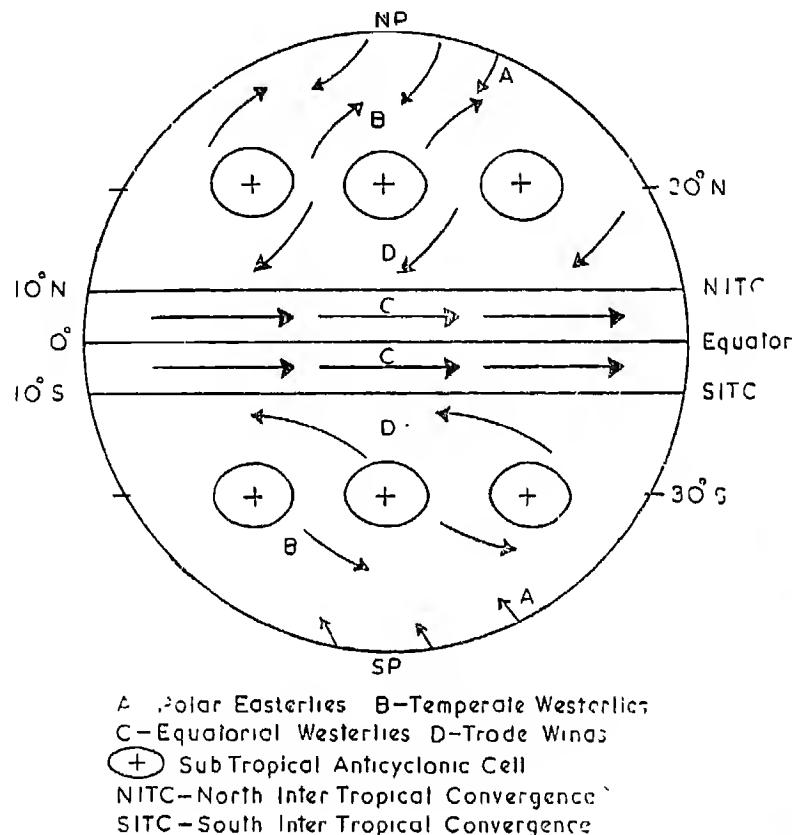


Fig. 71. Origin of Monsoons according to Flohn

produced by waves, cyclones, and convectional systems. The summer monsoon is very strong and has a high degree of constancy. It has two main currents : the Bay of Bengal current and the Arabian sea current. The south-west or summer monsoon is also characterised by breaks, bursts, and pulsatory movements. Breaks are the spells of one or more weeks during the height of monsoon in eastern

India. The burst is the sudden start of the monsoon activity with its heavy cloud and rainfall. When the westerly jet stream shifts from the south of the Himalayas to its north, the monsoon suddenly enters the Indo-Gangetic Plain. Pulsatory movements refer to alternate increase and decrease in the intensity of the monsoon winds along with that of the rainfall that occurs.

The winter monsoon in India is a gentle drift of air in which the winds generally blow from the north-east. Embedded in this return monsoon are many temperate latitude cyclones which cause sporadic rainfall. The rainfall caused by the winter monsoon is characteristic of the north-western parts and the Tamil Nadu coastal areas of India. Since the winter monsoon blows from land to oceans, by and large, it is less humid than the summer monsoon and the resultant rainfall is smaller in amount.

Outside India, in the eastern Asiatic countries such as China and Japan, the winter monsoon is stronger than its summer counterpart. Along the coast, the cold, continental, dry air masses and warm, oceanic humid air masses clash with each other to produce cyclones which then cause copious rainfall.

### Local winds

Local winds develop as a result of local differences in temperature and pressure.

They affect small areas and are restricted to the lowest levels of the troposphere. There are four basic types of local winds : hot, cold, convectional and slope.

### Local Hot winds

#### *Foehn or Chinook*

Foehn (termed Chinook in the U.S.A. and Canada) is the most well-known local hot wind in the middle-latitudes. It occurs on the lee-side of a mountain range and causes extremely rapid evaporation of snow or soil moisture (Fig. 72). The wind is dry and warm. It descends a mountain slope when a cyclone induces air to cross the range from the other side. The warm and moist air ascends the slope and causes rainfall. The latent heat of condensation keeps a high temperature in the ascending air which has become dry. The descending air becomes further heated by compression. The temperature of the Chinook is about  $15^{\circ}\text{C}$ . The wind helps animals grazing by removing snow from the ground, and also the early ripening of

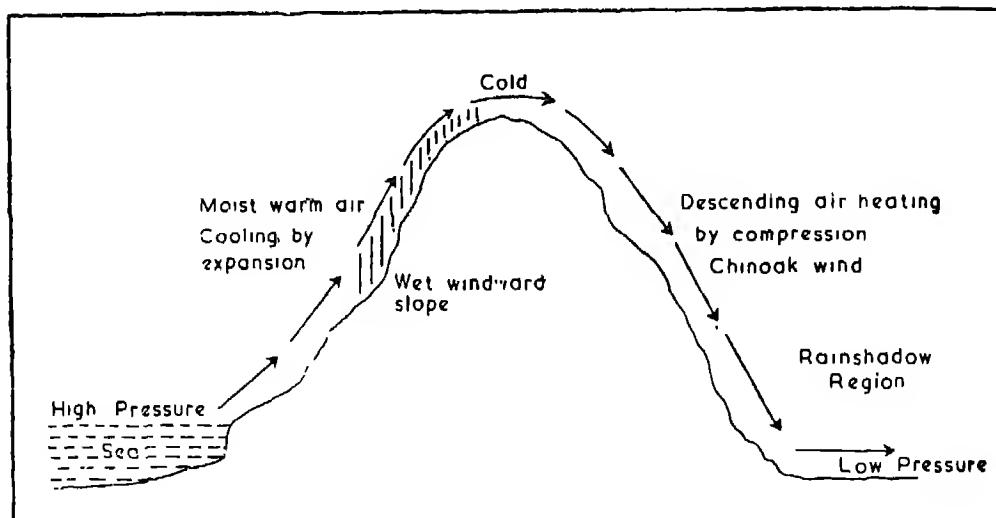


Fig. 72. Formation of Foehn and Chinook

grapes.

### *Simoom*

It is a hot, dry, suffocating wind or whirlwind which blows during the spring and the summer in the Sahara and the Arabian deserts. It carries with it dense masses of sand which greatly reduce the visibility, sometimes almost to zero. Also, it changes the shape of sand dunes which lie in its track. The wind originates in small areas of intense heating, very high temperature, and very low pressure. The temperature of air in simoom is more than  $32^{\circ}\text{C}$ . The whirlwind sucks loose sand particles upward in a spiral forming a sandspout. The simoom blows during the daytime.

### **Local Cold Winds**

#### *Mistral*

This cold wind flows in the winter from the higher lands and snow-capped mountains to the north on to the mediterranean coast of France. It is channelled through the Rhone Valley. It is a dry wind with high

velocity (Fig. 73). While the air pressure is high in the northern higher lands, the adjacent Mediterranean has low pressure associated with the travelling cyclones. The low pressure centres pull the cold, dense air toward themselves. The mistral is the most prevalent wind during the winter. It is very cold and very dry, and has a speed of more than 60 km. per hour. Even though the skies are clear, the mistral brings down the temperature below the freezing point. The mistral is so strong that gardens and orchards have to be protected from it by thick hedges of cypress trees, and many of the smaller houses have their doors and windows facing only on the south-eastern side,

#### *Karaburan*

It is the hot north-easterly wind experienced in the Tarim Basin of Sinkiang. The Karaburan blows during the early spring to the end of the summer when the interior of the Asiatic land mass is intensely heated. The wind is strong, has high speed, and sweeps up clouds of dust from the desert. It causes great discomfort by suffocating men and animals. Lighter dust particles are carried over to long distances beyond the desert where they are deposited to form loess. The sand blown by the Karaburan causes major changes in the courses of desert rivers.

### **Local Convectional Winds**

#### *Land and Sea-Breezes*

The land and sea breezes constitute a convectional system of winds. During the daytime, the land gets more heated than the adjacent sea and develops lower air pressure. The sea being cool develops higher pressure. The warm air of the land being lighter

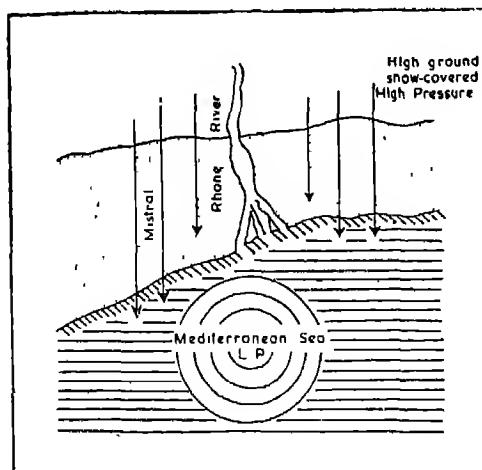


Fig. 73. Formation of Mistral

moves up and its place is taken by the cooler air coming from the sea. In the higher elevation, a return cool air current moves toward the sea, thus completing the convection cycle. The breeze moving on to the land from the sea is termed *sea breeze*.

In the night, the land gets cooler than the adjacent sea which remains relatively warmer. The higher pressure on the land induces the air to flow toward the lower pressure areas on the sea. This constitutes the *land breeze*. At higher elevations, again, there is a return current from the sea to the land.

The land and sea breezes help moderating the temperature of the coastal areas.

#### Local Slope Winds

##### Katabatic Winds

Katabatic winds (Fig. 74) or drainage winds are produced by the flow of cold air under the influence of gravity from higher to lower regions. During the night, the upper slope being more exposed gets more cooled by larger back radiation of heat. The lower tempe-

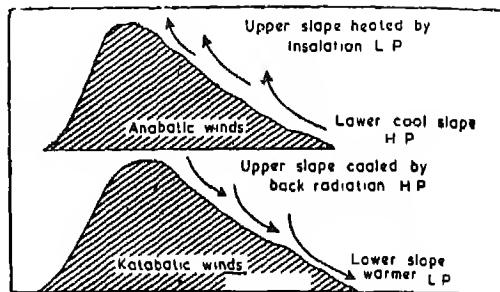


Fig. 74. Anabatic Winds and Katabatic Winds

rature produces high pressure. Air gets cooled, dense and heavy. The lower slope is relatively warmer and has lower pressure. Heavy air then slides down. The Katabatic winds are also termed *mountain breezes or gravity winds*.

##### Anabatic Winds

These are also termed *valley breezes* and occur during the day. The upper slope gets heated and develops low pressure, while the lower slope remains relatively cooler. The higher pressure than promotes the upslope flow of air and this produces the anabatic winds.

## E X E R C I S E S

1. What is the relationship between heating, temperature, and pressure?
2. How are the winds related to pressure differences?
3. What is the significance of the wind as an element and as a control in climate?
4. Define the pressure gradient.
5. Why does pressure decrease with altitude?
6. The distribution of pressure reveals cells more than belts. Why?
7. Name the main pressure belts. Describe them in terms of their location, shifts in location, and climatic attributes.

8. Explain, why the high-pressure belts are dry and the low-pressure belts humid ?
9. Explain, why the trades in the Northern Hemisphere have north-easterly direction ?
10. Describe, with a sketch, the formation and properties of the chinook wind.
11. How are the katabatic and anabatic winds formed ? What is their climatic significance ?

#### **Books for further studies**

Hare, F.K., *The Restless Atmosphere*, London : Hutchinson, 1966.

Sellers, W.D., *Physical Climatology*, Chicago : Chicago University Press, 1965.

Riehl, H., *Introduction to the Atmosphere*, New York : McGraw-Hill, 1965.



## CHAPTER

# Air Masses

An air mass is a thick and extensive part of atmosphere having a homogeneous character in terms of temperature and humidity. Within an air mass, there are horizontal layers arranged one over the other. In each layer, the conditions are more or less uniform. In motion, air masses appear to be large-scale currents of polar or tropical origin.

An understanding of air masses is necessary because of their relationship with (i) atmospheric disturbances, cyclones and storms, (ii) formation of fronts (iii) regional weather conditions, and (iv) transference of heat from lower to higher latitudes.

An air mass has two basic properties : vertical temperature distribution and moisture content. These properties affect the weather conditions of a region covered

by an air mass. The vertical temperature distribution is a measure of the warmth or coldness of the air mass. It affects its stability. When the air mass is stable, the vertical upward movement is restricted and precipitation is inhibited. When the air mass is unstable, the winds within it move upward and cause condensation and precipitation.

Air masses originate from areas which are termed *source regions*. These regions are extensive areas on the earth's surface having uniform characteristics. The air remains stationary for a long time on the surface and acquires the characteristics of the surface. The temperature and moisture conditions of the surface of the source region are acquired by air. Air is gradually changed into an air mass. The ideal source region should have uniform

surface and light divergent surface air movement. Both these conditions produce uniformity in temperature and humidity characteristics. Sub-tropical and tropical oceans, the Sahara in the summer, and the Arctic Plains of North America and Eurasia in the winter are some of the well-known source regions.

The moving air masses change not only their own characteristics but also of the regions which they invade and of the regions over which they travel. However, air masses retain the characteristics they acquire from the source region even after travelling over long distances. Air masses are essentially conservative in character. The properties of air masses change slowly in their new environments. In the areas of horizontal convergence, two different air masses meet and cause sharp changes in temperature and humidity. Within an air mass, changes are also caused by the vertical movement termed *convective instability*.

Air masses are classified on two bases : (i) source of origin, and (ii) modification. On the basis of the source region, there can be two primary types of air masses - *polar* and *tropical*. Since the source regions are both *maritime* and *continental*, we have four secondary types : *maritime polar*, *continental polar*, *maritime tropical*, and *continental tropical*.

Maritime air masses have moist characteristics and produce a large amount of precipitation. On the other hand, continental air masses are dry and produce a limited amount of precipitation. It is also to be noted that a continental air mass which has moved over the oceans has helped increased evaporation. In so doing, it develops some properties of the mar-

time air mass. When a maritime air mass travels over a continent, it does not immediately lose its moisture and, hence, is able to retain its original characteristics.

The properties of air masses are not only related to their source regions but also to several modifications which they undergo. There are two main types of modifications ; *thermodynamic* and *mechanical*. These modifications generally occur in combinations.

Thermodynamic changes are caused by the transfer of heat between the base of an air mass and the surface over which it moves. The degree of change is determined by the nature of the underlying surface, the path of movement of an air mass, the duration of travel, and the addition of moisture. The surface is located either in polar or in tropical regions. It can be either colder or warmer than the temperature of the air mass. When a warm air mass moves over a cold surface, its lower layers become cold. This creates a surface inversion of temperature and a condition of stability. Stability prevents the upward movement of air, and inhibits condensation and precipitation. Tropical air masses experience this change. When a cold air mass travels over a warm surface, its lower layers become warmer than its upper layers. This causes an increased lapse rate and instability. Instability promotes vertical movement of air, condensation, and precipitation. Polar air masses also undergo this type of change.

Evaporation from moist surface and from falling rain drops also add moisture to the air mass. The evaporated moisture also contains heat of condensation.

Mechanical changes are produced by

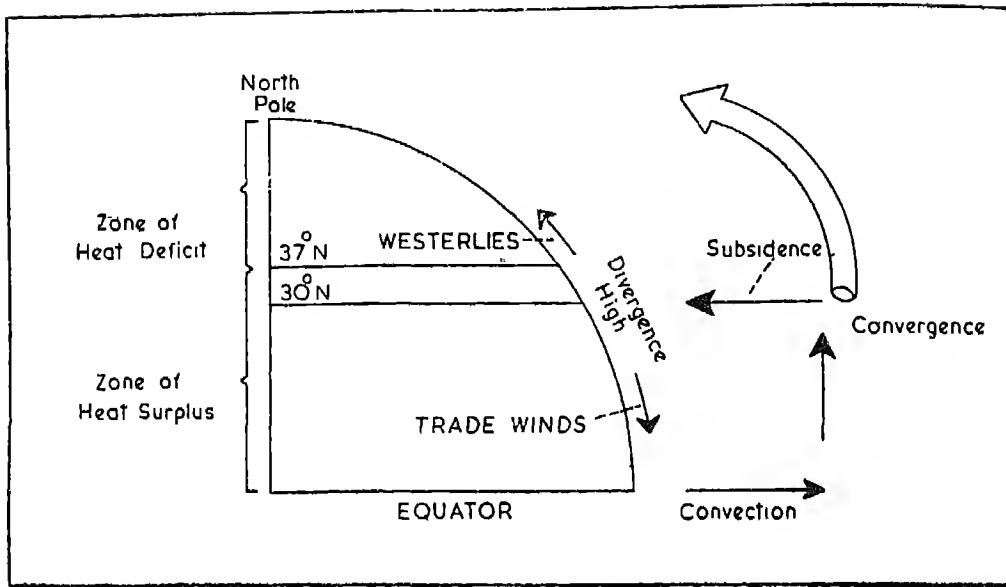


Fig. 75. Formation of a Jet Stream

turbulence and high level convergence and divergence. These changes result in the air mass becoming either stable or unstable.

#### Jet Streams

Jet streams have been termed *the high altitude rivers of air*. Actually, these are high velocity winds blowing at high altitudes. They are the essential parts of the wind circulation of the high troposphere.

A jet stream is a relatively narrow, tubular-shaped meandering flow of the winds moving from the west to the east (Fig. 75). In general, jet streams are located at altitudes of 5 to 12 km. Quite often, they occur along the tropopause. Jet streams exist in the Northern and Southern Hemispheres, but are stronger at some places. They are more pronounced in the Southern Hemisphere. In the Northern Hemisphere, they reveal wide

seasonal fluctuations.

The jet stream winds have velocities of 300 to 500 km per hour. The greatest velocities generally occur over the eastern parts of the continents and the western sides of the ocean basins. The lowest velocities occur in the longitudinal or west-east sectors near the surface subtropical high-pressure cells. Velocities change seasonally. The winter velocities are double those of the summer. The highest speeds in the winter occur along the Asian Coast, over South-eastern U.S.A., and in the region between North Africa and Indian Ocean.

The jet stream is circumpolar in nature. It completely girdles the earth in the Northern and Southern Hemispheres. Its average location is about 30° to 35° latitudes. The belt of jet winds is not continuous. The discontinuous segments are

1500 to 4500 km long, 150 to 600 km wide, and 1000 to 2000 metres thick.

The jet stream belt follows the annual march of the sun. It shifts toward the North Pole in the summer and toward the equator in the winter. In the summer, it is located between  $35^{\circ}$  and  $45^{\circ}$ N and, in the winter, between  $20^{\circ}$  and  $25^{\circ}$ N.

At places, a jet stream consists of several individual filaments of high, velocity air. In other parts, the filaments combine to form a single giant stream moving from the west to the east.

The jet stream, generally, is parallel to the latitudinal parallels. But it reveals north-south undulations as well. Very long ridges and troughs are common. Even the small waves of the jet stream have lengths of 6000 km.

The jet stream separates the cold air on its poleward side from the very warm air on its equatorward side. The jet is a belt of steep temperature and pressure gradients and is also termed *planetary frontal zone*.

Since the jet stream lies above the sub-tropical surface high and the sub-polar surface low, it is understood that it has to do something with the surface weather conditions and wind circulation systems. The jet stream is a high altitude circular wind movement. In the front of this circular movement, the winds are descending down and there is an upper air trough located above the surface high pressure cell. At the back, the winds are diverging from an upper air ridge. Just below this ridge near the surface the winds are converging and moving upward and creating a surface trough. Thus, the upper air ridge and the trough of the jet stream are related to the surface trough and ridge, respectively. Also, the meandering of the jet stream causes the cold air of the higher latitudes to invade the lower latitudes and lower their temperatures. Similarly the warm air from the lower latitudes invades the higher latitudes and raises their temperatures. Finally, the jet stream transfers heat from the zone of heat surplus to the zone of heat deficit.

## E X E R C I S E S

1. What is an air mass ? How is it different from the wind ?
2. Describe the polar continental source region.
3. What happens when a polar continental air mass moves over warm tropical oceans ?
4. What is meant by an unstable air mass ?
5. Why is a stable air mass dry ?
6. Describe a jet stream.
7. Discuss the shifting of a jet stream and its impact on weather.
8. Write an essay on the role of air masses in creating weather and climatic differences.

### Books for further study

Hare, F.K., *The Restless Atmosphere*, London : Hutchinson, 1966.

Landsberg, H., *Physical Climatology*, Dubois : Gray Printing, 1958.

Miller, A., *Climatology*, New York : E.P. Dutton, 1953.

Petterssen, S. *Introduction to Meteorology*, New York : McGraw-Hill, 1958.



## Atmospheric Disturbances and Cyclones

Cyclones constitute the most fundamental and climatically the most significant atmospheric disturbances. On the basis of the areas of their origin, cyclones are classified into two types : temperate and tropical.

### Temperate Cyclones

Cyclones are areas of low pressure. A centre of low pressure is surrounded by closed, concentric isobars, which indicate the movement of the winds toward the centre from all the quadrant and cardinal directions. Cyclones develop in areas of air-mass conflict and well-developed fronts. Temperate cyclones are concentrated in the middle latitudes between  $35^{\circ}$  and  $65^{\circ}$ .

Cyclones originate as waves in the westerlies and, hence, move from the west to the east. There are four

quadrants, two sectors, and two fronts in the structure of a cyclone. The warm sector and the cold sector have warm and cold air masses, respectively. The two fronts are : warm front in the south-eastern quadrant and the cold front in the south-western quadrant. The warm sector is the smallest and the cold sector is the largest in area. Most of the warm air masses are concentrated in the south-western and south-eastern quadrants, but the cold air mass is diffused throughout the cyclone.

The winds blow from different directions in the different quadrants. These are easterly and north-easterly in the north-eastern quadrant, and northerly and north-westerly in the north-western quadrant. In the south-eastern quadrant, they are south-easterly above the warm front and southerly below it. In the

south-western quadrant, the winds are north-westerly above the cold front and south-westerly below it.

Air has relatively less density in the cyclone. A cyclone is generally somewhat circular, but some are V-shaped with a broader part on the north and the long axis extending northeast-southwest in the Northern Hemisphere. These are elongated troughs (Fig. 76). The sub-angular shape is related to well-developed fronts which intersect with the isobars at blunt angles. Large cyclones having steep gradients are more numerous in the winter.

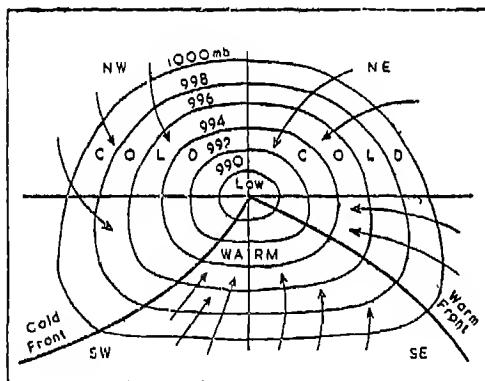


Fig. 76. Cyclone in the Northern Hemisphere

Converging winds raise up air located at the centre. This results in cloud-formation and precipitation.

Temperate cyclones are generally extensive. They have vertical thickness ranging from 9 to 11 km. and diameter of about 1000 km.

Cyclones are composed of two elements : unstable waves of surface fronts and surface cyclones built by the downward expansion of an upper air trough. Temperate cyclones reveal a sequence of

stages in their life history (Fig. 77). The

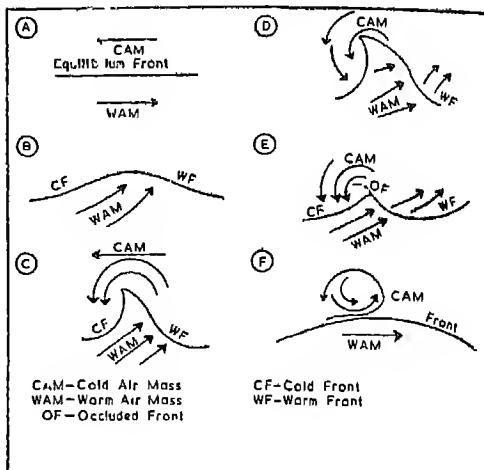


Fig. 77. Cold and Warm Air masses and Fronts

winds associated with air masses moving from the opposite direction produce a shear force which creates waves on the frontal surface. Some of these waves are stable and are damped out. Some are unstable and grow in size to become mature cyclones. Then air is drawn into the bulge, and as a result of the pressure gradient, rotation, and friction, it develops a cyclonic circulation.

In the first stage, the cold air mass on the poleward side and the warm air mass on the equatorial side move past each other in the opposite direction. Since there is no vertical displacement and it is stationary, the front is termed *equilibrium front*. The air currents are parallel to the front, and along the front there is a shear force and a wind wave. In the second stage, the wave begins to be formed along with two fronts, cold and warm, and the warm air mass impinges against the cold air mass on the warm front. In the third stage the wave becomes accentuated and

the two fronts meet at a sharp angle. The wave height increases and the warm air mass is trapped between the two fronts. In the next stage, the wave height reaches its maximum and the air currents of the two air masses acquire near-circular motion. In the fifth stage, the cold front overtakes the upper part of the warm front, changing its curl into the occluded front. The cold air mass pinches out the warm air mass on the surface. In the final stage, a large whirl of homogeneous air constitutes the cyclone.

### Tropical cyclones

Hurricanes or typhoons are the well-known tropical cyclones. They are notorious for their violence and for causing widespread destruction.

Hurricanes develop and mature over water bodies only. Hence, their major climatic significance is in causing widespread rainfall. Most of the hurricanes develop in a belt of  $8^{\circ}$  to  $15^{\circ}$  North and South latitudes.

Tropical cyclones are characterised by the following properties : (i) The isobars are circular and symmetrical. At the

centre, the air pressure is extremely low so that the pressure gradient is very steep and the winds are very strong. The wind velocities range from 120 to 200 km. per hour. (ii) Rainfall is torrential in nature but is distributed evenly around the centre. (iii) The area covered is relatively small, the diameter being only 150 to 500 km. The central part, termed the *eye* of the storm, has a diameter of only 10 to 50 km. The eye is calm and rainless. (iv) The contrasting air-masses are absent ; hence, the temperatures around the centre are relatively similar. (v) The winds form an upward-moving spiral, so there are no marked wind shifts. (vi) Hurricanes are far more common in the summer than in the winter. (vii) They move from the east to the west with the trades. (viii) The source of energy is latent heat of condensation.

Tropical cyclones occur in the south-western portion of North Atlantic Ocean, along the west coast of Mexico, south-western part of North Pacific Ocean, including the China Sea, North Indian Ocean, South Indian Ocean, and South Pacific Ocean.

### E X E R C I S E S

1. How are temperate cyclones formed ?
2. What is the relationship between air masses and cyclogenesis ?
3. What are the factors controlling the paths of temperate cyclones ?
4. Why are tropical cyclones so circular in form ?
5. How is heavy rainfall caused in tropical cyclones ?
6. Tropical cyclones are devastating in their effects. Why ?
7. What exactly is the role of fronts in the formation of cyclones ?

### Books for further study

Riehl, H., *Tropical Meteorology*, New York : Mc Graw Hill, 1954.

Gatbell, M.A. *Tropical and Equatorial Meteorology*, New York : Pitman Publishers, 1947.

Halfiner, *Dynamical and Physical Meteorology*, New York : Mc Graw Hill, 1957.

Johnson, J.C., *Physical Meteorology*, New York : John Wiley, 1954.



## Humidity and Precipitation

**H**umidity refers to the presence of water vapour in air. The amount of water vapour present in air is expressed in four different ways.

Vapour pressure refers to that part of the whole atmospheric pressure which is due to water vapour. It is expressed in millibars or inches or millimetres of mercury. Absolute humidity is defined as the weight of water vapour per unit volume of air. It is expressed as grams of water vapour in a cubic centimetre of natural air. Relative humidity is the ratio of the amount of water vapour actually present in air as compared with the maximum that could be contained by the same volume of air at the given temperature and pressure. Supposing air at  $70^{\circ}$  can contain 8 grains of water vapour per cu. ft. than only the 4 grains that it actually

contains, then the relative humidity will be only 50 per cent ( $4/8 \times 100 = 50$ ). When the relative humidity is 100 per cent, the air is termed fully saturated. The relative humidity changes in accordance with the changes in temperature and amount of water vapour. If the amount of water vapour remains constant but the temperature is increased there is a decrease in the relative humidity. It will increase if the temperature is reduced. In contrast, if the temperature remains constant, an increase in the amount of water will increase the relative humidity and a decrease in its amount will decrease the relative humidity.

Since the weight of air is proportional to the pressure, vapour pressure and specific humidity are similar. Any change in the pressure without any change in the

amount of water vapour changes these two indices. Absolute humidity is not a reliable index. It changes with the changes in the volume of air which are effected by expansion and contraction. Relative humidity determines the amount and rate of evaporation and hence is an important climatic factor.

### Distribution of Relative Humidity

#### Zonal .

Relative humidity is highest at the equator and decreases toward the poles. It is minimum in sub-tropical anticyclones. It increases from 30°N and S towards the poles following the decrease in temperature in the same direction. Following the apparent movement of the sun, the belts of relative humidity experience latitudinal shifting.

#### Seasonal :

The seasonal distribution varies with latitudes. Between 30°N and 30°S the average relative humidity is higher in the summer than in the winter. In higher latitudes, it is higher in the winter than in the summer because land is colder in the winter here. Thus the temperature is low, the specific humidity is the same, hence the relative humidity is higher.

### Evaporation

The process by which water, a liquid matter, is changed into water vapour, a gaseous matter, is termed *evaporation*. Three factors control the rate of evaporation ; (i) aridity, (ii) temperature, and (iii) movement of air. When and where aridity is high, air has a potentiality of absorbing and retaining a larger amount of moisture. In air with higher humidity, this potentiality is reduced hence evaporation is slow and small in amount. Simi-

larly warm water also experiences quicker evaporation when it is overlain by cold air. The lower layer of cold air is heated from below, becomes unstable, develops turbulence, and promotes evaporation. Evaporation is greater on the oceans in the winter than in the summer. Lastly, the greater the movement of air the greater is the evaporation. The movement replaces the moisture-filled layer by a drier layer which has a larger capacity of absorbing moisture.

### Condensation

Condensation is the process of change of state from water vapour to liquid water. When moist air is cooled either by rising or by coming into contact with cool surfaces, it may be cooled to a level when its capacity to hold water vapour is exceeded by the actual amount present in it. Then a part of water vapour which is in excess condenses into a liquid form. In this process of condensation a certain quantity of heat is given up. This is termed *latent heat of condensation*. The temperature at which condensation normally begins is termed *condensation temperature or dew point*. In free air, condensation results from cooling around very small particles termed *condensation nuclei*. The most active condensation nuclei are termed *hygroscopic particles* which attract moisture on them even at temperatures above the dew point and when the relative humidity is less than 100 per cent.

It is clear that for condensation to take place the temperature of air must be close to or below the dew point. The dew point is closely related to the relative humidity of air. Also, the amount of cooling needed to effect

condensation is influenced by air temperature and relative humidity. When the temperature is low and the relative humidity high, only a slight amount of cooling is necessary for condensation. In contrast, when the temperature is high and the relative humidity low, a much greater amount of cooling would be necessary.

The amount of cooling and the relative humidity of air determine not only the amount but also the rate of condensation.

#### *Forms of Condensation*

Condensation can also be classified on the basis of temperature at which the dew point is reached. Condensation can take place when the dew point is (i) lower than 32°F and (ii) higher than the freezing point. In the former condition, white frost, snow, and some clouds, and in the latter condition dew, fog, and clouds are produced.

Condensation at or near the earth's surface results in the formation of dew, white frost, fog, and mist, and in free air in the formation of clouds.

**Dew** : The moisture deposited in the form of water droplets on the earth's surface or on the objects near the earth's surface, such as blades of grass, is termed *dew*. The ideal conditions for the formation of dew are a clear sky, little or no wind, high relative humidity, and relatively long nights. Under these conditions, the earth radiates back a large amount of heat and its surface becomes cooler than the atmospheric layer immediately overlying it. In its own turn also, this layer becomes chilled by radiation and conduction. When its temperature is reduced below the dew point, condensation takes

place and dew particles are formed. The dew point itself must be above 32°F in order that dew be formed.

**White Frost** : White frost consists of particles of frozen moisture formed on the earth's surface when condensation takes place at a dew point below 32°F. The ideal conditions for the formation of white frost are the same as those for the formation of dew. The air temperature must be at or below 32°F or 0°C.

**Fog** : Fog comprises a dense mass of small water drops or smoke or dust particles in the lower layers of atmosphere. Fog results from the cooling of air below its dew point. Cooling is caused by radiation, conduction, and mixing of warm and cold air masses.

Three types of fogs have been identified : (i) radiation fog, (ii) advection fog, and (iii) frontal fog. Radiation fog is the commonest type and needs for its formation the following conditions : (a) air should have been under a cloud cover with rain falling through it the day before the fog occurs, (b) pools of air, cooled to an excessive degree, collected in depressions or valleys, (c) a surface inversion of temperature, (d) slight air movement, and (e) cloudless skies on the night before the fog occurs.

Advection fog is formed through the transportation of warm, moist air over cold surfaces. This type occurs frequently along the sea-coasts and shores of large inland bodies of water. It is common on the lands in the winter and on the oceans in the summer.

Frontal fog is formed along the front separating cold and warm air masses. Cooling is caused by the forced ascent of air due to convergence and by saturation of the

cold surface layer of air by rainfall from the over-running warm air aloft. Frontal fogs are common in the cool temperate latitudinal belt where fronts are frequent.

**Mist :** Mist is a type of fog in which the visibility is more than 1000 metres but less than 2000 metres. It becomes fog when the visibility is less than 1000 metres.

**Clouds :** Cloud is a mass of small water drops or ice crystals formed by the condensation of the water vapour in free air at a considerable height above the earth's surface. Clouds display infinite varieties of forms. Two main types are recognised according to their shape and mode of formation : (i) *Cumuliform* or heap clouds which attain great vertical heights, and (ii) *stratiform* or layer clouds. According to height and form, there are ten types of clouds : (i) low clouds (up to 2000 metres) which include *stratocumulus*, *nimbostratus*, *cumulus*, *cumulonimbus* and *stratus*; (ii) Medium clouds (up to 6000 metres) which comprises *altocumulus* and *altostratus* and (iii) high clouds (up to 10,000 metres) which include *cirrus*, *cirrostratus* and *cirrocumulus*.

Condensation leading to the formation of clouds and to the occurrence of rain and other forms of precipitation needs the ascending of air currents. This is helped by *adiabatic temperature changes* and *adiabatic cooling*.

### Adiabatic Temperature Changes

When air moves upward, it is subject to lower pressure and it expands. In contrast, when it moves downward, it is compressed by higher pressure surrounding it. Expansion results in cooling and compression in heating, although heat is neither added nor subtracted. This kind

of change in heat and, hence, in temperature is termed *adiabatic temperature changes*.

The rate of adiabatic heating and cooling of dry or non-saturated air is constant, regardless of the temperature of the air. It is about  $10^{\circ}$  per 1000 metres change in altitude. This is termed *dry adiabatic rate*. This rate is far more rapid than the *normal lapse rate*. These two rates are entirely different. The former refers to the changes in an upward moving body of air, while the latter refers to the changes occurring through static layers. At an elevation of 3000 metres, an upward moving air pocket which has a temperature of  $50^{\circ}\text{C}$  at sea-level will have a temperature of  $20^{\circ}\text{C}$ , following the dry adiabatic rate, while the temperature of the surrounding air, following the normal lapse rate, will be  $32^{\circ}\text{C}$ .

The non-saturated air moves upward following the dry adiabatic rate and reaches an elevation and a temperature at which condensation takes place. This temperature is termed *condensation level*. It is clear that the condensation level of rising air masses having different initial temperatures and relative humidities will be different. An air mass having high relative humidity and low temperature initially will need to move upward to a lower height than an air mass having low relative humidity and high temperature to effect condensation. Condensation level in the first case will be lower and the difference between it and the initial temperature will be smaller than in the second case. Thus, the air mass A starting with a temperature of  $80^{\circ}\text{C}$  will reach its condensation level at a temperature of  $50^{\circ}\text{C}$  and at an

elevation of 3000 metres. The difference temperature of  $30^{\circ}$  will reach its condensation level at  $10^{\circ}\text{C}$  and at an elevation of contrast, the air mass *B* starting with a 2000 metres. The difference in tempera-

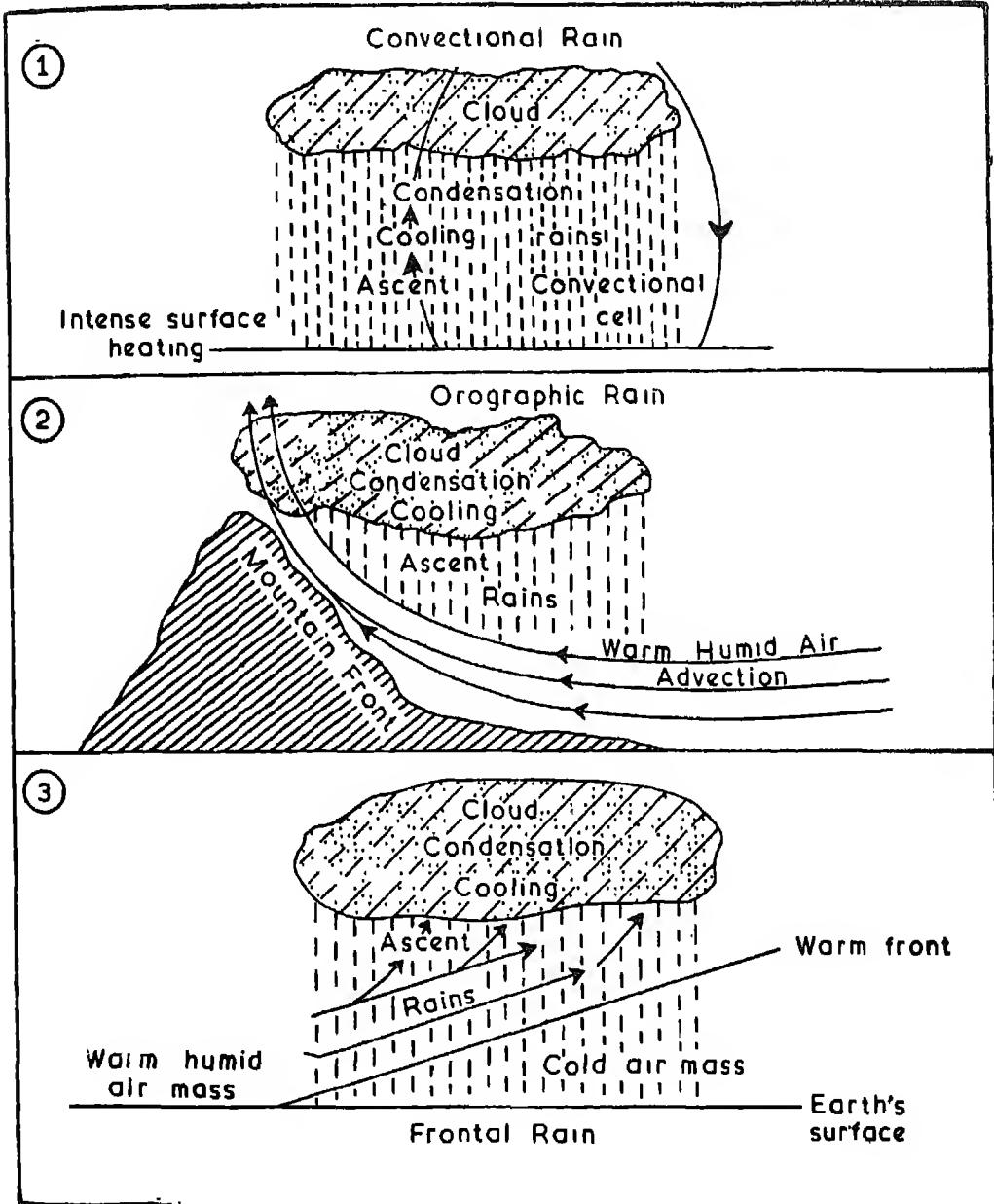


Fig. 78. Convectional Rain, Orographic Rain and Frontal Rain

tures will be 20°C. Thus, the warmer air has to be cooled to a greater extent by moving up to greater heights to effect condensation.

After condensation has taken place, the latent heat of condensation will be added and, thus, the air mass will move up and cool at a slower rate. This slower rate of cooling of the non-saturated moving air mass is termed *wet adiabatic rate*. The wet adiabatic rate is not constant like the dry adiabatic rate but varies with the temperature of the air. The wet adiabatic rate of the air mass of 80°C is 2.5°C per 1000 metres which is much less than that of the air mass of 30°C, being about 6°C per 1000 metres. In the air mass A the amount of the liberated and added latent heat of condensation is much greater than in the air mass B.

#### **Adiabatic Cooling and Precipitation**

Adiabatic cooling is the only process by which the temperature of extensive and thick masses of air is reduced below the dew point. The resulting condensation is on a vast scale and the precipitation is abundant. Almost all the earth's precipitation is the result of adiabatic cooling. Adiabatic cooling produces clouds and all precipitation falls from clouds.

#### **Precipitation**

After condensation has taken place in the free air in the form of rain-water, snow, sleet, or hail, these particles, fall down attracted by gravity. This constitutes *precipitation*. Thus, two major forms of precipitation are liquid and solid.

**Types :** On the basis of its origin, three types of precipitation are recognised : (i) convectional, (ii) orographic, and

(iii) frontal.

**Convectional rain** (Fig. 78) is caused by convectional ascent of warm and humid air to great heights. During hot, summer days, the earth's surface, locally, is intensely heated. The surface air is also heated. It expands and is forced to rise by the cooler, heavier air above and around it. As the air rises, it becomes cool, condensation takes place, water vapour particles are changed into water particles, the particles join each other to form larger particles heavier than those which could be supported by the upward moving currents of air. Then they start falling (Fig. 79). At the same time the latent heat of condensation is released

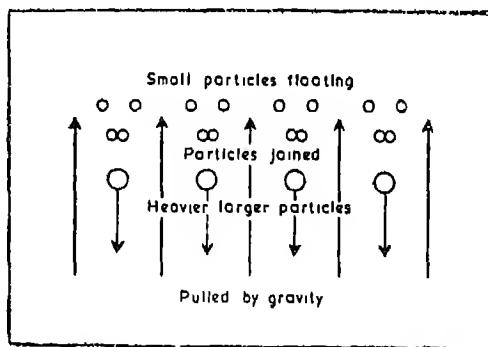


Fig. 79. The Mechanism of Falling of Rain Drops

which further heats the air and forces it to continue moving upward. Further condensation takes place and more of precipitation follows. Thus, convectional precipitation works for a long time as a self-generating mechanism. Convectional rain is heavy but highly localised and is associated with the minimum amount of cloudiness.

**Orographic rain** (Fig. 78) occurs where warm, humid air strikes landform barriers,

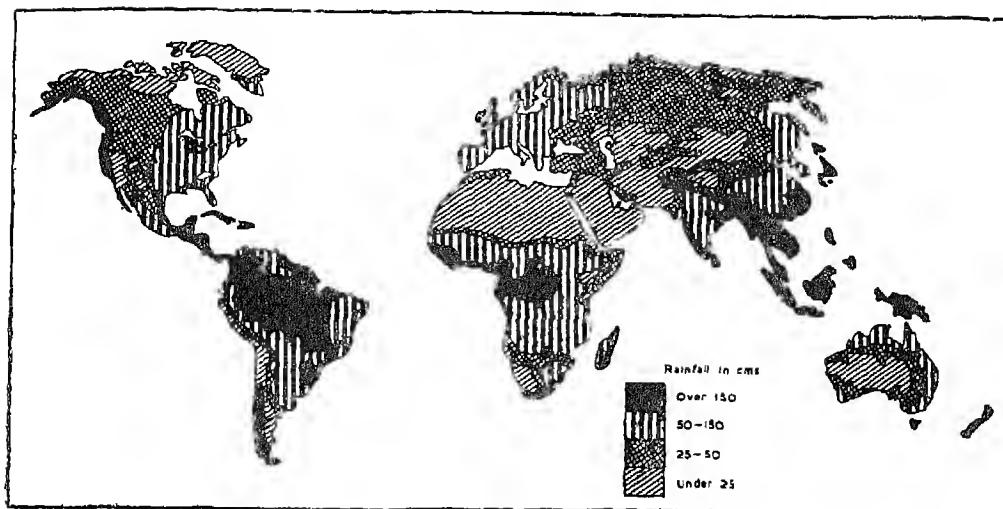


Fig. 80. Distribution of Rainfall

such as mountain ranges, and rises up. The subsequent sequence is similar to that of the convectional rain. Orographic rain is heavy on the windward side of the mountain range, while the leeward side is termed *rain shadow region* which is arid to semi-arid in nature. Orographic rain occurs in a belt along the mountain range and, hence, decreases in amount as the distance from it increases. Much of the monsoon rainfall in the western Ghats or in the Himalayas is orographic in nature.

*Frontal rainfall* (Fig. 78) occurs where a warm and humid air mass slides along the warm front on a cold air mass. Since the warm front is gently sloping, the warm air mass rises slowly and the rainfall is extensive. Since fronts are often found in cyclones, frontal rainfall is also cyclonic in nature and is termed *cyclonic rainfall*.

#### Zonal Distribution of Rainfall

The latitudinal distribution of rainfall is termed *zonal distribution*. Three factors

affect this distributional pattern : (i) the great latitudinal zones of horizontal atmospheric convergence and divergence, (ii) the distribution of land and water, and (iii) the alignment of highlands. The first factor is the most important (Fig. 80).

The average annual precipitation for the whole earth is about 975 mm. On the land it is about 660 mm. but on the oceans it is about 1100 mm.

There is a strong primary maximum of about 1900 mm. in a belt of 10° width on both sides of the equator. In each hemisphere, the amounts decline poleward. Lower rainfall of about 800 mm. is observed at latitudes 20° to 30°N and S. From these sub-tropical locations, rainfall again increases. A secondary maximum of about 1000 mm. occurs at 45° to 55°N and S latitudes. Poleward from these latitudes rainfall again decreases. Beyond 75°N and S latitudes there is an absolute zonal minimum rainfall of 250 mm. only.

## EXERCISES

1. Name the factors controlling the amount and rate of evaporation.
2. How does condensation take place ? What are the different forms of condensation ?
3. What is the dew point ? How is it related to the amount of moisture ?
4. Define absolute and relative humidity. Which among the two is most significant to climate and why ?
5. Explain the difference between dew, fog, snow, and cloud.
6. What are the necessary conditions for precipitation to take place ?
7. Discuss the processes of adiabatic heating and cooling.
8. Discuss the salient features of the world distribution of rainfall and the associated controlling factors.

## Books for further study

- Critchfield, H., *General Climatology*, New York : Prentice Hall, 1961.
- Trewartha, G., *An Introduction to Climate*, New York : McGraw-Hill, 1954.
- Sutcliffe R.C., *Weather and Climate*, Weidenfeld & Co., 1966.
- Mason B.J., *Clouds, Rain, and Rainmaking*, : Cambridge University Press ; Cambridge, 1962.





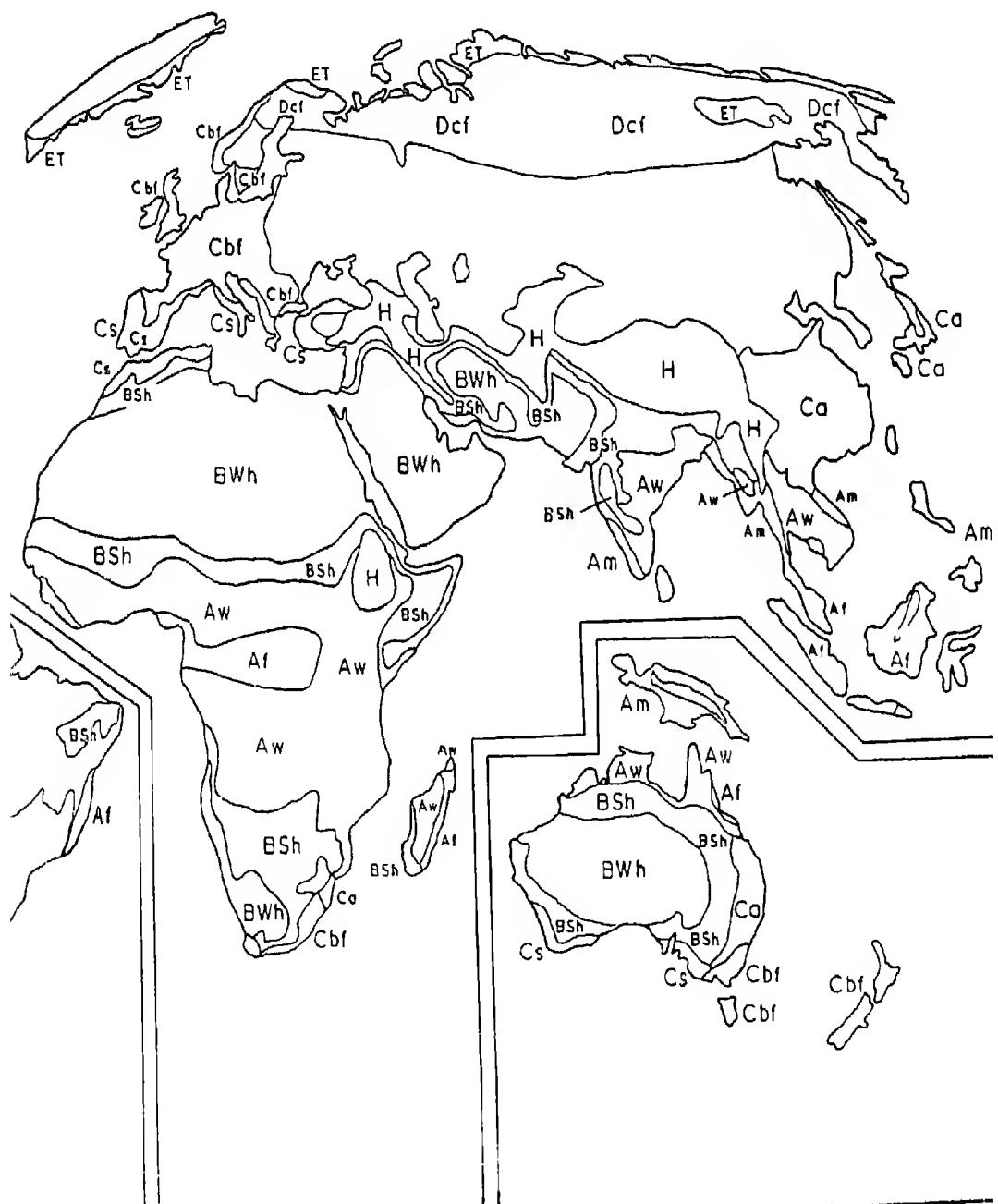


Fig. 81. Types of Climate

## CHAPTER 19

# Classification of Climates

It is well known that different regions of the earth have different climates. Different combinations of climatic controls produce many variations of climate from place to place and, thus, a large number of climatic types. Mapping of climatic regions helps us to identify their spatial distribution on the earth. This needs identifying the main climatic types by a process of classification. For this purpose, we have fine bases of classification : temperature, rainfall, evaporation, evapotranspiration, and water balance.

On the basis of temperature, the earth's climates can be classified into three broad groups : the tropical, the temperate or the middle-latitude, and the polar.

Rainfall can help in identifying dry, wet, seasonally wet, and seasonally dry climatic types.

Evaporation is controlled by temperature. In using evaporation as a basis of identifying climatic types it is matched against rainfall. Where evaporation is greater than rainfall, the climate tends to be *dry*; where it is less the climate tends to be *humid*. This relationship is applied not only to the year, but also to the seasons. Thus, we have *wet, seasonally wet, dry, and seasonally dry* climatic types.

Evapotranspiration is the amount of moisture lost by evaporation from the ground and by transpiration from the plants. The relationship of evapotranspiration and rainfall again leads to the identification of *humid, seasonally humid, dry, and seasonally dry* climatic types.

The relationship between water surplus and water deficiency is expressed by *water*

*balance*. If the former is greater than the latter, the climate is *humid*; if it is less, the climate is *dry*. Water surplus occurs when precipitation exceeds potential evapotranspiration. When precipitation is less than potential evapotranspiration, water deficiency occurs.

We shall now discuss the main features of the two well-known systems of climatic classification. There are two well-known types of classification: one suggested by Thornthwaite and the other by Koeppen. We shall describe here the main types of climates based on Koeppen's classification.

#### Principal Climatic Types

There are six major groups of climates: (i) Tropical rainy, (ii) Dry, (iii) Humid mesothermal, (iv) Humid microthermal, (v) Polar, and (vi) Undifferentiated highlands (Fig. 81). On the basis of the area covered, human occupancy and human utilization, the following principal climatic types can be identified:

- (i) Tropical rainy : Tropical rainforest, monsoon, tropical savannah
- (ii) Dry : Tropical and sub-tropical desert, tropical and sub-tropical steppe
- (iii) Humid mesothermal : Mediterranean, China, West European
- (iv) Humid microthermal : Taiga
- (v) Polar : Tundra
- (vi) Undifferentiated highlands

The complexity of the combination of climates and their distribution in a continent depends on its size, relief features, and climatic controls.

#### Tropical Rainforest

This climatic type occurs in a belt 0° to 25°N and S. The Amazon Basin, Congo Basin, and Indonesia are typical representatives of this type. In this type, temperatures are high throughout the year and the annual average is about 27°C. The daily range is about 11°C, while the annual range is only about 3°C. Rainfall is heavy and occurs throughout the year. The annual average is about 250 cm. The movement of the winds is only slight. High humidity and little air movement raise the sensible temperature to very high levels.

#### Monsoon climate

It is also known as the monsoon rainforest climate. This type occurs typically in South-eastern Asia, western Guinea coast of Africa, eastern Amazon valley, West Indies, and Guiana Coast lands of South America. The annual average temperature is about 26°C and the annual range is about 3°C. The maximum temperature occurs in May before the summer rainfall maximum in June and July. The annual rainfall amounts to about 300 cm. The basic characteristic is the series of monsoon winds which experience a complete reversal of the direction between the summer and winter seasons.

#### Tropical Savannah

This climate is typical of tree-studded grasslands in the tropical and sub-tropical latitudes. Tropical savannah is bounded by tropical rainforest climate toward the equator and by dry climates toward the poles. It occurs in Venezuela, Colombia, Guianas, north of Amazon in South America, Sudan and Veld in Africa, northern Australia, India, Burma, Thailand and Vietnam. The annual average

temperature is about  $23^{\circ}\text{C}$  and the annual range is 5 to  $6^{\circ}\text{C}$ . The annual rainfall is about 160 cm. There is a distinct dry season during the winter in the Northern Hemisphere. The rainfall varies greatly from year to year. Floods and droughts are quite common.

#### *Tropical and sub-tropical Desert*

The tropical and sub-tropical desert climate is surrounded on all sides, except the western, by low latitude steppe climatic type. It occurs in the Sahara, the Thar, Arabia, south-western U.S.A., south-western Africa, and Central Australia. This climate is dominated by the sub-tropical anticyclones and is the most nearly rainless of all the climatic types. The annual average is about 25 to 40 cm, but this average is meaningless because rain occurs only once in several years. The rainfall variability shows a departure of more than 40 per cent from the normal. The rainfall is of cloud-burst and thunder-shower type which produces a very high intensity; in a single shower as much as 6 cm of rain falls. Occasional high floods are, therefore, quite common, separated by long periods of absolute drought. Skies are clear and sunshine abundant. Evaporation is 20 times the precipitation. The average annual, summer, and winter temperatures are  $38^{\circ}$ ,  $40^{\circ}$ , and  $15^{\circ}\text{C}$ , respectively. The diurnal range is more than  $16^{\circ}\text{C}$ .

#### *Tropical and Sub-tropical Steppe*

This climate surrounds the low-latitude desert climate and occurs in southern Australia, Mesopotamia, Arabia, southern Iran, north-western Mexico, and north-western India. The annual average temperature is  $21^{\circ}\text{C}$  and the annual range is about  $13^{\circ}\text{C}$ . Rainfall is not only small

but highly variable. The annual rainfall is 30 cm. Steppes located on the poleward side of the deserts receive the maximum rainfall during the cool seasons, while those located toward the equator receive it during the warm season. Passing cyclonic storms are characteristic of cool seasons.

#### *The Mediterranean Type*

This climate occurs in the warm temperate latitudes. The areas covered extend around the Mediterranean Sea, Central California, Central Chile, southern tip of South Africa, and south-western and south-eastern tips of Australia. This climatic type is characterised by dry summers, unusually mild wet winters, and a large incidence of sunshine. The average annual, winter, and summer temperatures are  $16^{\circ}$ ,  $10^{\circ}$ , and  $25^{\circ}\text{C}$ , respectively, producing an annual range of  $16^{\circ}\text{C}$ . The annual rainfall amounts to 40 to 60 cm. The winter rainfall is due to middle-latitude fronts and cyclones and the summer drought is related to sub-tropical anticyclones.

#### *The China Type*

This climate is the eastern locational counterpart of the Mediterranean type. It occurs in China, south-eastern U.S.A. Argentina, Uruguay, southern Brazil, Japan, and eastern coastal belt of Australia. The average annual temperature is  $19^{\circ}\text{C}$ , while the annual range is about  $17^{\circ}\text{C}$ . Rainfall is distributed throughout the year and has an annual average total of about 120 cm. Late summer and autumn are the dreaded seasons of hurricanes and typhoons.

#### *The West European Type*

This climate is representative of the cool-temperature latitude group of climates. It

occurs between 30° and 60°N and S latitudes in the western part of Europe, North America, South America, and south-eastern coastal strip of Australia. The climate is characterised by the invasion of polar fronts, cold polar air masses, and middle-latitude cyclones during the winter. Weather remains highly variable and unpredictable throughout the year. The annual, summer, and winter averages of temperatures are 10°, 15° and 7°C, respectively. Rainfall occurs throughout the year and the annual total is about 140 cm. The winters are rainier than the summers.

#### *The Taiga Type*

This climatic type is named after the coniferous trees of Siberian regions. The climate extends in two large belts, both extending in the east-west direction, in North America from western Alaska to Newfoundland and in Eurasia from Norway to the Kamchatka Peninsula. The climate is dominated by polar and arctic air masses. The annual, summer, and winter averages of temperatures are 5°, 13°, and -3°C, respectively. The annual range is about 16°C. About 6 to 8 months have temperatures below zero. Cyclonic rain along the coast and convectional rainfall in the interior are the characteristics

of the climate. The total annual precipitation is less than 50 cm.

#### *The Tundra Type*

This climate occurs in east-west trending narrow belts north of 60°N latitude in North America and Eurasia. In general the tundra area is continental in nature. Extremely cold winters are the principal characteristic of this type. The ground is covered with snow and ice for about 8 months. Purga and buran winds shower snow particles. The summer and winter temperatures are 10° and below 0°C, respectively. Two to four months have temperatures above zero. The total annual precipitation is about 30 cm. It is in the form of rain during the summer and dry snow during the winter.

#### *The Undifferentiated Highlands Type*

This type covers the Tibetan Plateau, the Himalayas, the Rockies, and the Andes mountains and a small part of the Alps. Altitude and aspect play significant roles in controlling the temperature and precipitation of this climate. High insolation, low temperature, low air pressure, large diurnal ranges of temperature, and relatively large rainfall and snow at higher altitudes are common. The most important characteristic is the vertical gradient in all the principal climatic elements.

## EXERCISES

1. Which are the two well-known climatic classifications ?
2. Name the principal bases of climatic classification.
3. Name the major climatic types of the world.
4. Enumerate the principal features of the Mediterranean and the West European types of climates.

Books for furthur study

Kendrew W.G., *The Climates of the Continents*, London : Oxford University Press, 1953.

Blair, T.A., *Climatology*, New York : Prentice-Hall, 1942.

Critchfield H., *General Climatology*, New York : Prentice-Hall, 1961.

Trewartha, G., *An Introduction to Climate*, New York : McGraw Hill, 1954.





## **UNIT IV**

# **Hydrological Cycle**



## CHAPTER 20

### Hydrological Cycle

**H**ydrology is the science that studies water in all its aspects especially in relation to its occurrence in streams, lakes, wells, oceans and as snow and ice. It also studies its discovery, uses, control and conservation. Water exists in a dynamic condition with its circulation from the oceans to the atmosphere, thence to the land, and back to the oceans (Fig. 82). This circulation is termed the *hydrological cycle* or the *water cycle*. The hydrological cycle interconnects the lithosphere, the hydrosphere and the atmosphere.

However, there are several intervening agencies which either intercept or accelerate the hydrological cycle. (Fig. 83.) This means that it is not a simple bilateral transformation of moisture. There is always an associated change in the stage of moisture and in the location of mois-

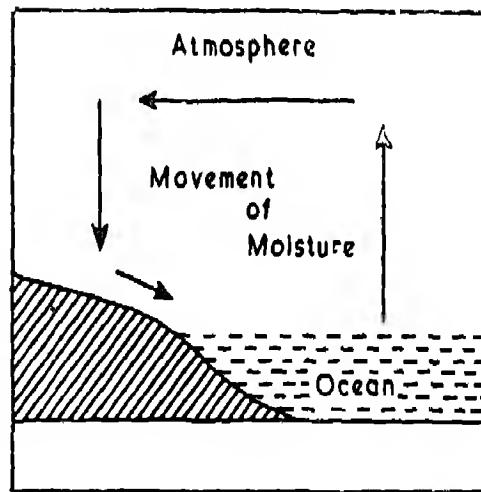


Fig. 82. Simple Hydrologic Cycle

ture, e.g., the moisture that goes into the atmosphere may be precipitated into water, dew, snow, ice, frost and the like. Similarly, water collects in various forms. The water that comes down from the atmosphere may enter a river, a lake,

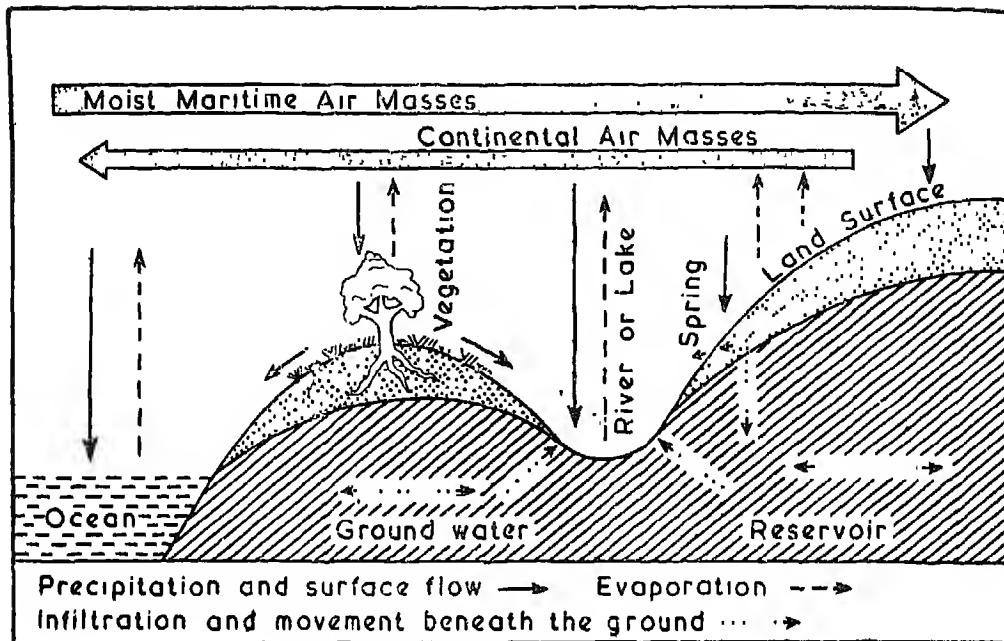


Fig. 83. The Hydrologic Cycle

may become a part of a glacier or underground water. As a result of these changes in the stage and location, the progress of the hydrological cycle is retarded. Exemplifying further, if 25 grams of water vapour were to enter from the ocean into the atmosphere and then, after condensation return to the ocean, the cycle would have operated without intervention. It is the tempo with which the cycle is operating that is slowed down whenever there are changes in the state and location. The movement of water from such intervening locations back to the ocean and the change from one state of water into the other are always slow.

Let us clarify this with an example. We may assume that there are two intervening variables a river and a lake. The ideal hydrological cycle operates on the ocean,

where there is a continuous interchange of water in the seas and moisture in the atmosphere. However, if the rain, instead of falling directly on the ocean, partly falls on the land and collects in a river, the river takes a long time transporting the water to the ocean. Some water may also get locked up in a lake basin ; this water would first evaporate into the atmosphere and then through condensation re-enter the ocean.

Vegetation cover, glaciers or underground water may also act as intervening factors. In all cases, the main characteristic involved is holding back a part of the water belonging to the hydrological cycle and then releasing it very slowly.

The hydrological cycle involves several processes as is clearly evident from its functioning. These processes result in the

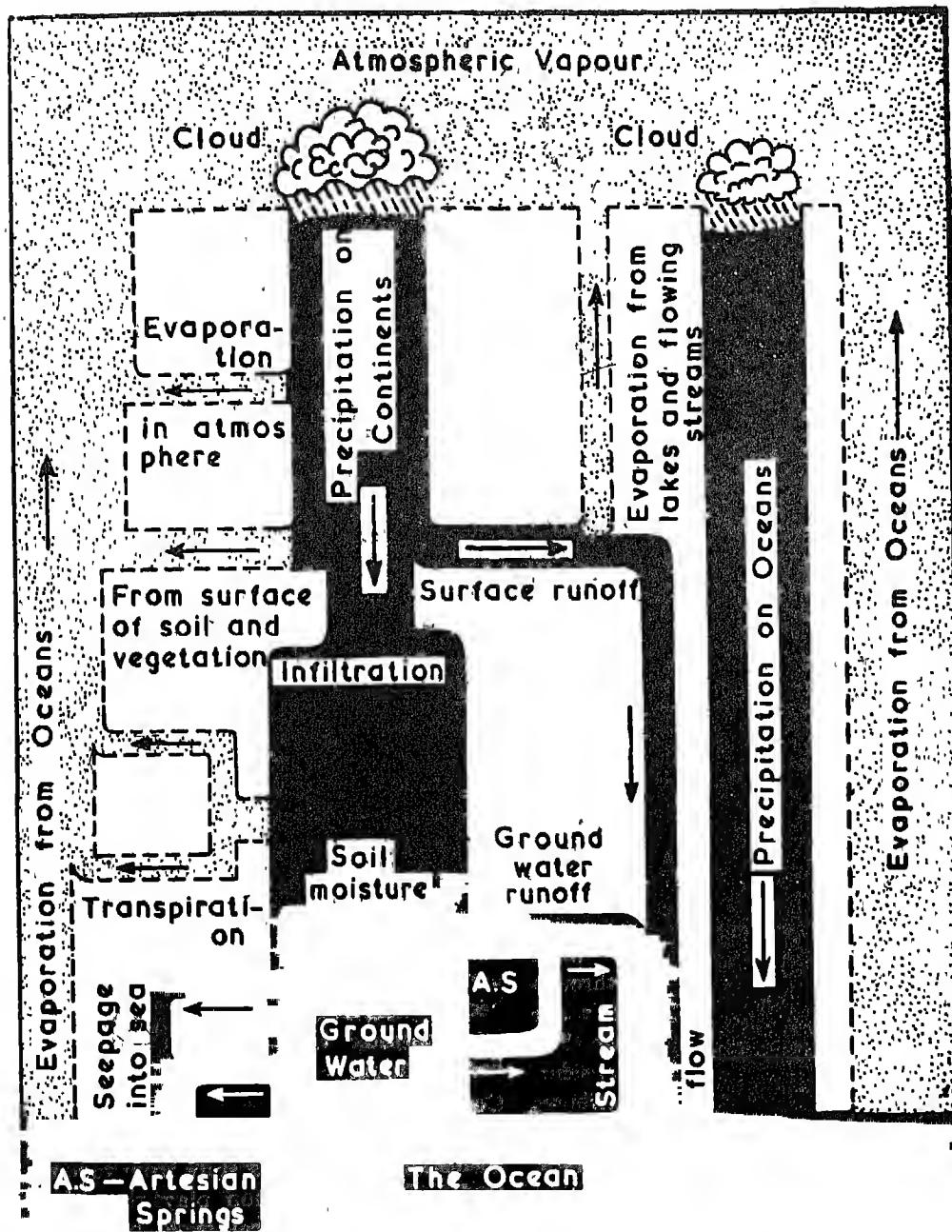


Fig. 84. A Model of Hydrologic Cycle

movement of water from the ocean to the atmosphere and back to the ocean (Fig. 84.) These processes include : evaporation, transpiration, air mass movements, condensation, precipitation, infiltration, surface run-off, and underground water behaviour.

### **Evaporation**

Evaporation is the only mechanism by which water from the oceans reaches the atmosphere. This is undoubtedly the most significant source, but equally important is the role of evaporation from other bodies, such as vegetation, soil, rivers, ponds, lakes, and even from the falling rain. Over the world as a whole, evaporation is always greater over the oceans than over the continents. This is primarily because over the oceans there is no dearth of water to be evaporated. However, as regards the other sources, the actual evaporation is very largely controlled by the characteristics of surface from which evaporation takes place. Evaporation from vegetation is controlled by type of vegetation, its distribution density and foliage. The larger the area covered by vegetation, the greater would be the amount of evaporation.

### **Transpiration**

Transpiration is the process by which plants having absorbed moisture through their roots return it, in the form of water vapour to the atmosphere through their leaves. This process leads to a considerable loss of moisture, but contributes little to the mechanism of the hydrological cycle. Vegetation, if efficient in transpiration, would add to the hydrological cycle, since it is all the time sucking water from below the surface and bringing it on to the surface. For example, in desert areas

vegetation being scarce, the amount of transpiration is small and the hydrological cycle is retarded. In contrast, dense forests accelerate the hydrological cycle.

### **Air Mass Movement**

Air masses are the principal agencies of transference of moisture from the oceans to the continents and back. The amount of moisture transferred by these thick enormous bodies of air is very large. The air masses involved in the hydrological cycle are primarily of two types : (i) continental air masses and (ii) maritime air masses. Obviously, it is the latter which carries a large amount of moisture into the continent. Both these types of air masses carry moisture, but the maritime air masses moving from the oceans to the continents carry larger amounts of moisture than the continental air masses moving from the continents to the oceans.

Air mass movements show the regional aspects of the hydrological cycle. The humid tropical maritime air mass moving toward the poles is cooled, which leads to condensation, causing precipitation on the continents. Moreover, when the cold stable polar air masses move to the lower latitudes, they become warmer, and the lowest layer coming into contact with the warmer surfaces becomes hot. As a consequence, it expands, ascends, and becomes unstable. Thus, it is converted into maritime tropical air, resulting in heavy rainfall.

### **Condensation**

Condensation is the process by which a substance changes its state from vapour to liquid. Condensation plays the major role in the hydrological cycle by transforming vapour again into water on the land and the sea.

### Precipitation

Precipitation refers to the deposits of water, either in liquid or solid form, which reach the earth from the atmosphere. Therefore, precipitation is an integral component of the hydrological cycle. It is, in fact, the major step in the completion of the hydrological cycle both on the land and the sea. Precipitation includes not only rain, but also sleet, snow and hail which fall from the clouds, and dew and hoar frost. Rainfall is often used synonymously with precipitation to denote the total amount of water in all forms deposited on a given area. Hence, if precipitation is slow, even when the moisture evaporated from the oceans has been enormous, the efficiency of the hydrological cycle would be reduced. Therefore, conditions which are favourable for precipitation indirectly become very important in the hydrological cycle, whether the precipitation is orographic, convectional or cyclonic.

### Infiltration and Surface Run-Off

Consequent to precipitation, two processes start operating immediately, infiltration and surface run-off, each involving some amount of evaporation too. Infiltration and surface run-off are both interdependent processes. Infiltration refers to the rate at which water (derived from precipitation) percolates into the soil. Run-off amounts to the excess of precipitation over infiltration. Changes in the underground water seepage affect the surface run-off. The underground seepage is in itself affected by the surface material, the slope of the terrain, the nature of the bedrock, and the density of vegetation. The climatic controls are temperature and intensity of rainfall.

### Behaviour of the Underground Water

Surface water, after infiltration, becomes a part of the underground water, which moves to vegetation, soils, rivers and oceans. Thus, it is again either directly or indirectly released in the hydrological cycle. The last two processes complete the hydrological cycle in that the moisture which was once evaporated from a water body (ocean) is returned to it.

It is evident that there are certain essential pre-requisites for the operation of the hydrological cycle. When heat and moisture are abundant, as in the tropics, the hydrological cycle is particularly active. In dry climate the cycle becomes slow, while in very cold climates, the operation of the cycle is highly limited. Low activity of the hydrological cycle would naturally cause low rainfall.

### Ground Water

Water in its fluid form can penetrate very minute pores of any materials, and it is due to this property of water that it enters the soil and later the rocks underlying, through the minute open spaces left between different particles of the material or through the openings created in rocks by faults, fractures, and joints. This process of water going into the ground is known as *infiltration*. The water that has entered the earth's body and occupies open spaces in the soil or bed-rock is known *sub-surface water*. That part of the sub-surface water which is held in the soil within a few metres of the surface is termed *soil water*. On the other hand, that part of the sub-surface water which is held in the openings in the bed-rock or deep within the thick layers of transported overburden is often referred to as

ground water.

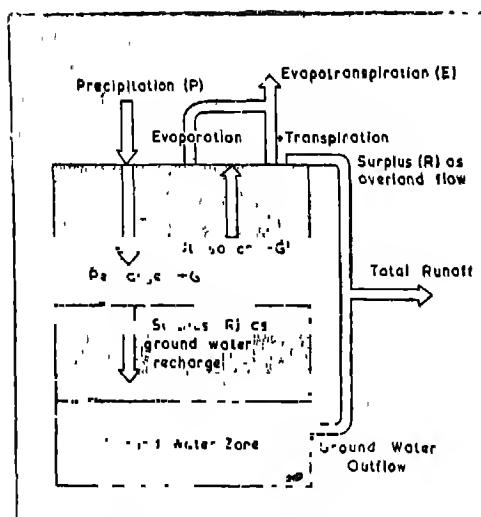


Fig. 85. Soil Water Balance

Once having entered the process of infiltration, the underground water moves in different ways. Immediately below the soil water belt, at the top of the bed-rock, the gravity percolation of water starts. Water goes deeper into bed-rock upto the water table under the force of gravity. At the water table, there is a movement of water, going against the gravity, which is known as *capillary rise*. The smaller the pores of the bed-rock, the higher will be the capillary rise.

If the ground water removes some parts of the bed-rock and creates some cavities through which it flows freely making channels, the flow of water, in the same manner as on the surface (*i.e.*, streams), is observed.

The *porosity* of a rock material refers to the total volume of pore space present in a given volume of rock. It stands for the water-holding capacity of the rock material and a porous rock does not necessarily

allow water to flow through it.

Another property of rocks is the *permeability*. The permeability refers to the capacity of a rock to allow water to flow through it. The pore-spaces, if sealed from the neighbouring ones will not allow water to flow, and so a rock, although porous, will not be permeable. Thus to be permeable, the pore spaces of a rock need to be interconnected. It may be noted here that a permeable rock is always also a porous one whereas a porous rock is not always permeable.

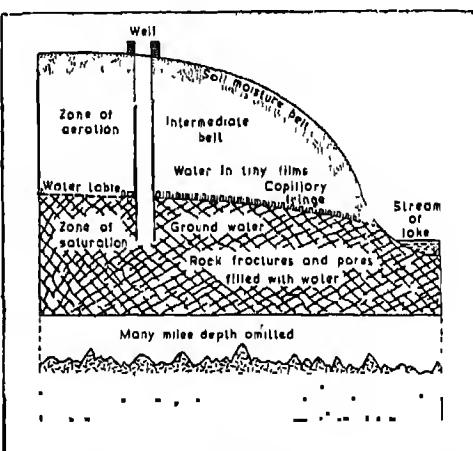


Fig. 86. Zones of Subsurface Water  
Water Table

Below a certain level which is not very deep in the humid regions but very deep in the arid regions, all the fissured and porous rocks are saturated with water (Fig. 86). The upper surface of this saturated zone is called the *water table*. The water table broadly follows the relief of the ground and is arched up under the hills (Fig. 87). The zone above the water table through which water percolates down to the water table is known as the *zone of aeration* or the *zone of suspended water*.

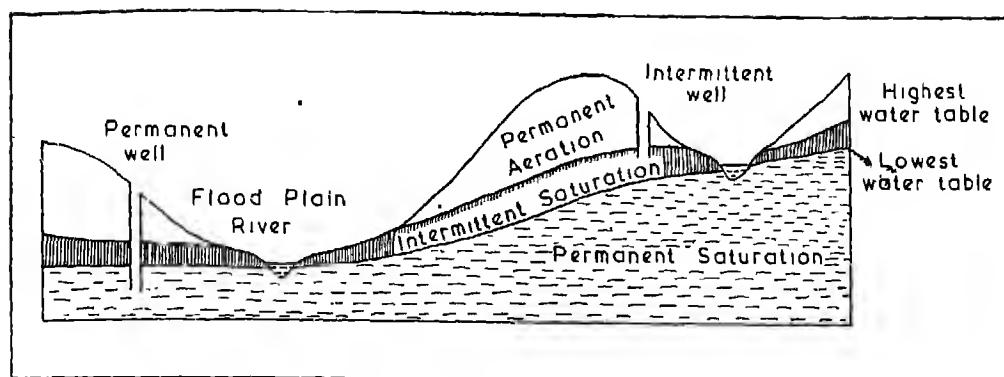


Fig. 87. Relation of Water Table to Surface and Changes in it

Water in the subsurface behaves differently in different types of rock materials and, consequently, the water table is also affected likewise. If at some place above the main body of ground water there is an impervious stratum in the zone of aeration, some ground water is held above this stratum and this water is known as the *perched ground water*. The upper surface of the perched ground water body is known as the *perched water table* (Fig. 88).

rainfall on the ground surface (Fig. 89). During extreme dry weather, the water table goes deeper. The deepest level the water table ever attains is known as the *permanent water table*, and below it is a zone of permanent saturation. On the other hand, during extremely wet weather conditions, the water table reaches very near the land surface, and between the highest water table and the permanent water table is the zone of intermittent saturation. The zone between the highest water table and the ground surface is known as the *zone of permanent aeration*.

The water table responds to the relief of the ground above, as has already been noted, and follows it in a subdued manner. The water table changes also as a response to the changes in the permeability of rocks, because different rocks vary in their property of permeability and so display varying degree of their water-holding capacity.

The ground water is discharged out of the ground continuously, and so the amount of water stored in the underground reservoirs, if not replenished, may become

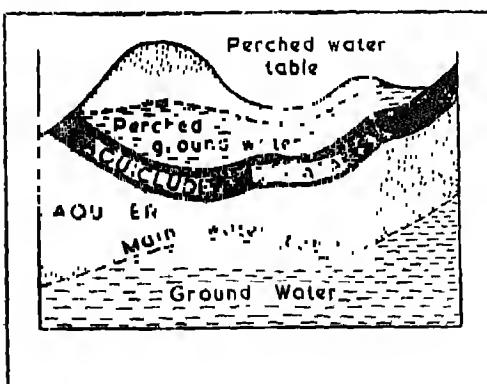


Fig. 88. Perched Ground Water

The water table changes its position in response to the changes in the amount of

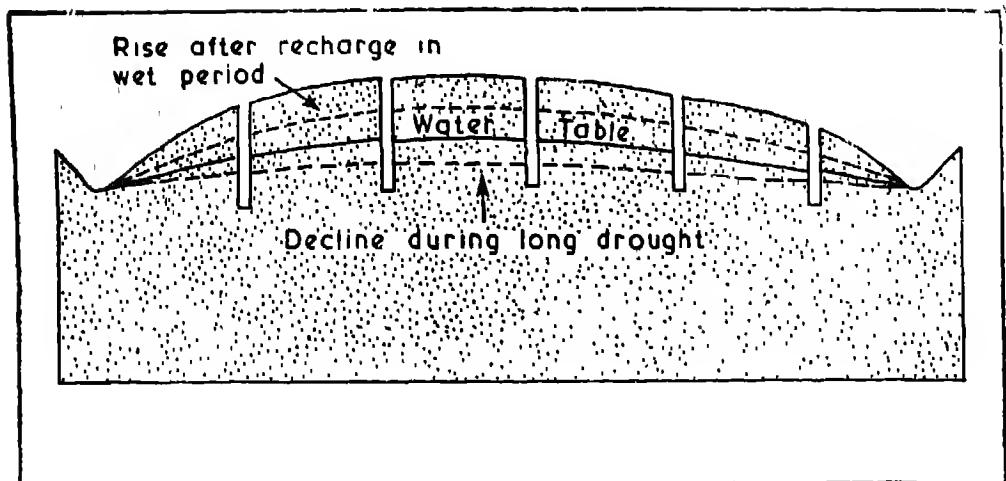


Fig. 89. Rise and Fall in water table according to Natural Variations in Annual Recharge

exhausted after some time. But it is interesting to note that the ground water is continuously recharged also through the downward seepage of the surface water, either from rain or melted snow or from streams and lakes supplied by rain and snow. The rain water reaches the water table after having infiltrated through the zone of soil water and percolated through the zone of aeration.

The amount and rate of recharge of the ground water depends on the rainfall, its distribution in space and time, and the intake facilities, such as the permeability of rocks, the structure of area, etc.

#### **Springs : Geological and Topographical Relationships**

A spring is a concentrated outflow of the ground water at the surface through an opening in a rock mass, in the form of a current of flowing water. A spring, therefore, is found at a place where there is an aquifer exposed at the surface

or where an aquifer is overlain by a previous alluvial or detrital cover. The water of the springs may be supplied by a free-moving body of the ground water controlled by the slope of the water table (water table springs) ; or by the water held between the two layers of impervious rocks known as confined water (artesian springs) ; or by the water forced up from the great depths by other forces than the hydraulic pressure (geysers, volcanic, and thermal springs).

Springs can occur in different geological and topographical conditions. At places where the layers of previous rocks are inclined, water flows down through the aquifer and oozes out at a point where the lower edge of the previous stratum meets the ground surface (Fig. 90). If the pervious stratum is directly on the surface and above the water table, the spring created is termed as the perched water spring. On the other hand, if the aquifer

has layers of aquiclude both above and below it, the spring in such condition is called the *confined water spring* (Fig. 90).

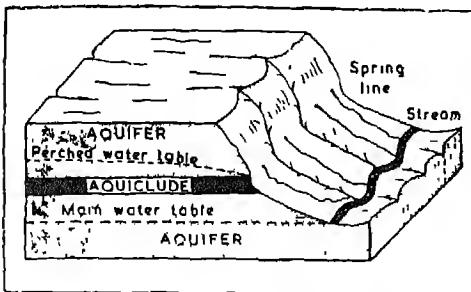


Fig. 90. Rock Structure and Springs

Some springs are generated at the line of a fault on the surface (Fig. 91). A fault may bring some aquifer strata in direct contact with the impervious strata, and so the ground water in the aquifer may be held up and not being allowed to percolate down. Such water finds its way out of the ground at the surface expression of the fault plane. In such conditions if there is a low ground below the springs having poor drainage facilities, there may develop a marsh just below the line of springs.

In the rock having a well-jointed structure, water may enter the rock through joints and may come out of it at places where the water table meets the ground surface or where further percolation is hindered by some rock having no interconnected joints (Fig. 91).

If there is a dike, having the impervious material, exposed at the surface as an outcrop and has the pervious material on both sides of it, then the ground water from the higher side may come out in the form of a spring and after running on the surface of the dike, it may again enter the pervious rock below it (Fig. 91).

In the limestone regions, if the limestone strata are underlain by the impervious strata, the ground water, after entering the limestone and making cavities by dissolving it, makes its way down to the lower surface of the limestone strata and comes out of the ground at places where this surface meets the ground surface in the form of springs. In some later stages when a considerable amount of limestone has been dissolved, these springs may be converted into limestone caverns (Fig. 91).

At places, springs are found at the lower edge of the talus cones and the landslides (Fig. 91). Water enters the loose fragmented material and percolates down along the surface of the unfractured impervious bed-rock and comes out as springs at the lower edges of the loose material (Fig. 91).

At places where there are deposited pockets of the pervious material over the impervious strata, the water entrapped in such pockets finds its way out at the lower edges of the pervious pockets, resulting in the springs called the pocket springs (Fig. 91).

#### Wells-Aquifer wells, Percolation wells and Spring wells

Wells are man-made excavations. These are made by mechanical drilling or manual digging into the earth's surface in order to extract the ground water stored in the underground rock strata for the human use or for irrigating the crop-fields. Wells can be in the form of dug pits or they may be in the form of shafts sunk into the ground up to the water-bearing strata, as the tube-wells.

The dug-wells can be of various types. The spring wells, essentially, consist of a hole carried down to the first impervious

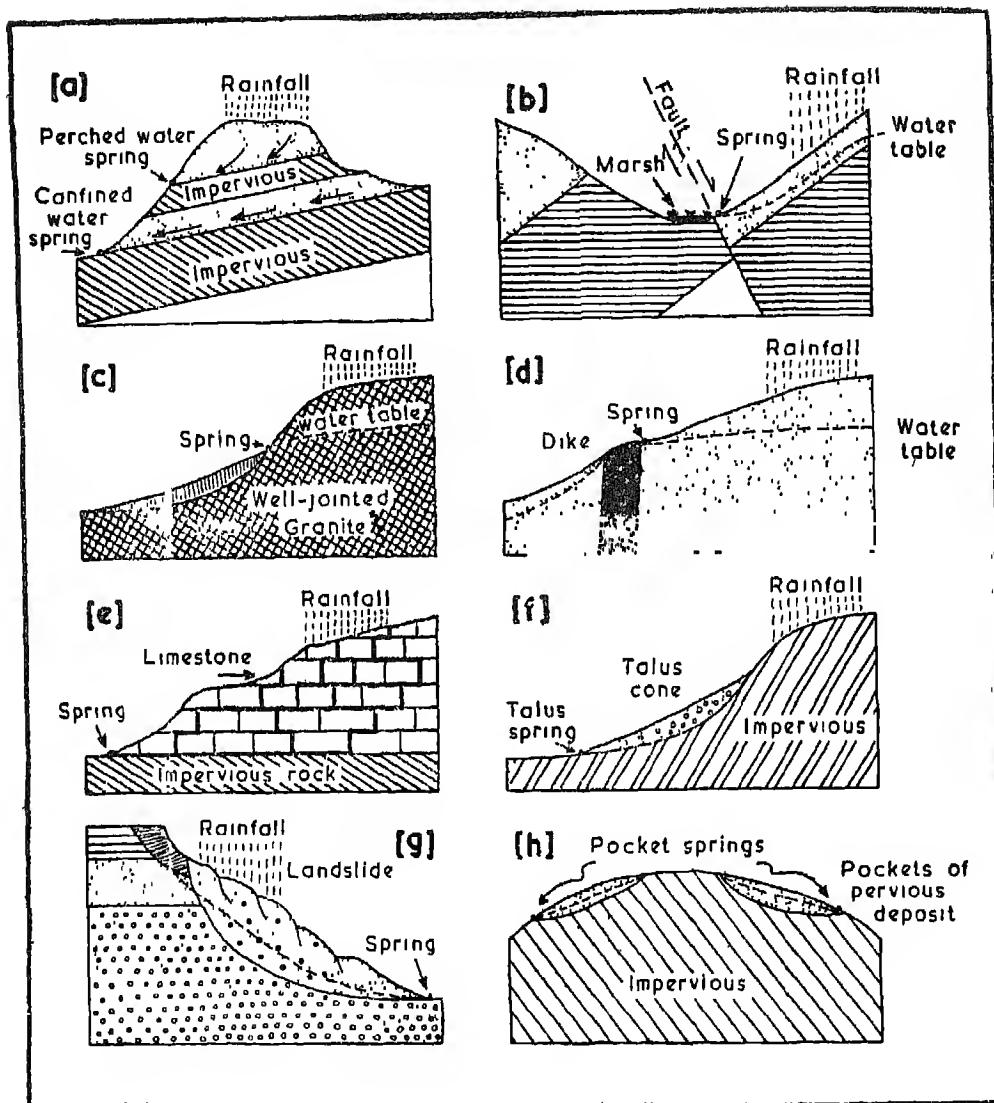


Fig. 91. Formation of Springs

layer of the clay which overlies a layer of the water-bearing sand (Fig. 92). The layer of the clay is then pierced for a smaller hole, and if the sand-bed below contains water in a sufficient quantity, there is an immediate rush

of water into the well until it rises approximately above the clay layer. The layer of the clay left at the bottom of the well acts as a beam to support the well, and the clay, being an aquiclude material, does not allow the water of the well to

percolate down. Such wells in India are

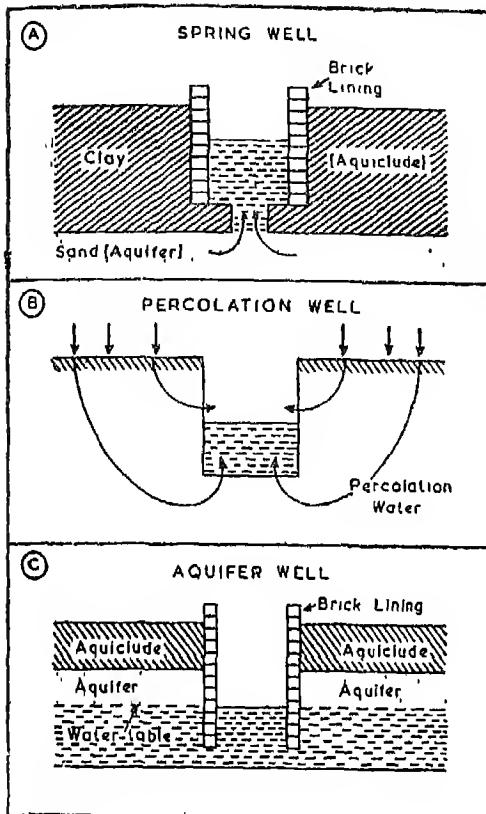


Fig. 92. Spring well, Percolation well and Aquifer well

found in the Pleistocene Terraces in the Himalayan foothills and the Ganga Plain. The spring wells are more or less permanent suppliers of water and can withstand long periods of droughts.

The second type of dug-wells is the percolation wells, which are generally found in the Recent Flood Plains (Fig. 92). These wells get their water from the percolation of the surface water which finds its way into the wells through the openings in the sides and the base of the well. These wells are not lined with

bricks so that supply of water to the wells is not hindered. Such wells are not permanent suppliers of water and they may dry up even during a short spell of dry weather. The advantage of such unlined percolation wells is that they are cheaply constructed; they can be dug within a short time; and they can be dug near the fields without any particular difficulty.

The third type of wells is the aquifer wells which are the wells dug to the depth of the water table into the aquifer. The level of water in these wells is up to the level of the water table. Such wells are permanent sources of water (Fig. 92).

#### Artesian wells

An artesian well normally gives out water continuously, the water being forced upward due to the hydraulic pressure created due to the outlet of the well being at a lower point than the level of the source of water (Fig. 93). The name artesian is derived from Artois, the French

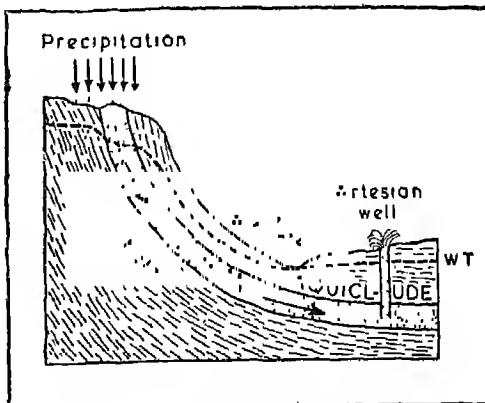


Fig. 93. Geological conditions for Artesian flow

province where some of the earliest artesian wells were constructed. The

possibilities of the artesian flow of water are found at places where the rock strata are in the form of a synclinal fold and the layers of the rock are comprised of some pervious rocks which have the impervious rock-beds, both above and below it, so that the water entrapped in the impervious strata cannot move out until some suitable opening in the adjacent impervious bed is found. Another condition necessary for the artesian flow is that the point where the aquiclude strata are outcropping and from where the water enters the ground, should be higher than the outlet of the well, so that considerable hydraulic pressure is created so that the water gushes out at the ground automatically. Greater the vertical fall from the point of entry to the point of exist of water, the greater will be the hydraulic pressure, and so the water will gush out of the ground with a great force. When the hydraulic pressure is very great, the water comes out from the ground in the form of a fountain.

Thus, from the above discussion we see that for an artesian well the following four conditions are necessary : (i) an inclined or synclinal aquifer bounded on both sides by water-tight beds ; (ii) exposure of the aquifer on the ground at a considerable height so as to create sufficient hydraulic pressure ; (iii) a sufficient amount of rainfall in the catchment area so as to furnish sufficient supply of water ; and (iv) the absence of any means of escape of the confined water except through wells.

A well-known example of an area having conditions favourable for the artesian flow is the London Basin where permeable chalk-beds function as an aquifer which

is enclosed by the London-clay above and the Gault-clay below which are impervious. When the first wells were sunk there, water used to gush automatically to the ground level, but now due to excessive extraction of water, the supply of water has decreased and so pumps have to be used. Conditions favourable for the artesian flow are also found in North and South Dacota near the Black Hills, in the United States. The area of Queensland and adjoining new South Wales in Australia has the largest artesian basin in the world. In India, the porous sandstones of the Himalayan foothills having synclinal structure provide very favourable conditions for the artesian flow. Good artesian conditions are also found along the Narmada Valley to the north of the Satpura range, where aquifer conglomerate beds are overlain by the impervious crystalline rocks. Artesian conditions are also found in the Neyveli lignite-mining area in the Tamil Nadu state and also in Pondicherry.

#### Geyser

The term geyser is applied to those hot springs which eject columns of hot water and steam at more or less regular intervals to heights varying from a few centimetres to hundreds of metres. The term is derived from an Icelandic proper name Geyser meaning gusher or spouter.

If a person stands near a geyser, he will observe the following sequence of action of the geyser during the time period between two gushes - the water in the vent is clear in the lulls between two eruptions and one can see far down into the spring ; just before a new eruption, he will see a white cloud rising from the vent, which is a swarm of tiny gas bubbles

which expand as they rise and near the surface they become two to five centimetres in diameter ; and within a few moments the column of water and steam is ejected high into the air. This cycle goes on without break.

#### *The causes of Eruption*

The vent of the geyser is filled with hot water, which is charged with hot gases. At great depth, at the lower end of the vent, there is a reservoir of water which is in contact with the hot rocks, and the water here is hotter than that in the vent. But the water in the reservoir is prevented from boiling because of the pressure created by the column of water above. As the water here reaches near the boiling point, a large amount of vapour is released which ascends the vent of the geyser. As soon as these vapour bubbles reach the surface, the pressure on the hot water in depth is relieved and the water flashes violently into a vast volume of foam and spray, which surges up with an irresistible

force, hurling itself up to a height of about 60 metres (Fig. 94).

#### **Location and Geological Relationship**

Geysers are mostly found in regions of recent volcanic activity, where the lava has not fully cooled down at great depths below the earth's surface. The ground water coming in contact with these heated rocks is ejected as hot water and steam. There are three regions having a great number of hot springs and geysers ; Iceland, Yellowstone National Park (U.S.A), and the North Island of New Zealand. Some geysers have also been reported from Alaska, Kamchatka, Japan, The Malay Archipelago, Eastern Tibet, and Morocco.

The water of the geysers and hot springs is alkaline, and carries silica in solution which is deposited on the walls of the vent and around the mouth of the vent in the form of a cone. The rocks below the sinter cover are recent volcanics and

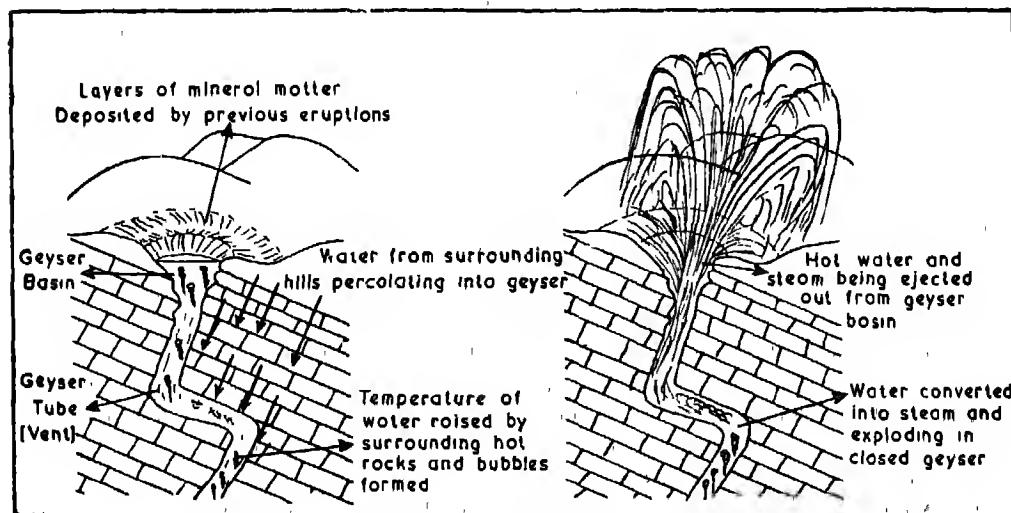


Fig. 94. Formation of Geyser

are still hot and so convert the ground water into hot water and steam, which are ejected out through the geyser vent with a great pressure created by vapour and expanding hot water.

### **Surface Phase of the Hydrological Cycle**

The sub-surface phase of the hydrological cycle starts at the point where water enters the ground. About 25 per cent of the average annual rainfall runs off the surface of the ground, a considerable proportion is evaporated, and the rest about one-half or more sinks into the ground. The path the underground water follows varies with the geological structure of the area concerned. Some rocks are aquifers, such as sandstones, whereas other rocks, such as shales are aquiclude. The rocks with interconnected joints allowing water to flow act also as pervious rocks. There is another set of rocks which affect the flow of the underground water. They are limestones and dolomites which dissolve into water, and so in the place of the dissolved rock cavities are formed through which the streams of the underground water flow.

In the regions having the limestone strata, either exposed on the ground surface or having a layer of the aquifer above it, the path of the ground water is different. The water charged with carbon dioxide can dissolve some amount of limestone and so after entering it makes small cavities which are gradually enlarged by the action of the water. If at the bottom of the limestone bed it is exposed to the surface, the water comes out as springs. On the other hand if below the limestone bed there, again, is the aquifer, the water enters into that and flows as shown

earlier.

Ultimately, the sub-surface phase of the hydrological cycle is completed when the ground water emerges along the lines or zones where the water table intersects the ground surface. Such places often are channels of streams, floors of marshes, and lakes or ocean.

It is very important to note that water entering the ground at the divide does not follow a direct path adhering, close to the water table, to the point of seepage. Water follows paths which are upwardly concave. The most rapid movement is found near the point where the water is discharged into the stream.

### **Development of Limestone Topography (Karst)**

The typical limestone topography is named after its occurrence in the Karst area of Yugoslavia. Kras in Yugoslavian language refers to limestone plateau. Limestone or Karst topography refers to the topography of limestone or dolomite which has been created by the solution action of the underground water and to a limited extent by the surface water. Karst topographic features develop on both over and under the ground.

Karst topography occurs in various climatic regions. Cuba, Tabasco, and Jamaica are located in tropical rainy climatic regions. New Mexico is arid. The Rohtas Plateau in Bihar experiences monsoon climate. While Tabasco has a coastal location, the Mexico Karst region has an interior continental location. Kurnool, Bastar, Kangra, Jabalpore, and Solan have landscapes of well-developed Karst topography.

The Karst cycle operates through underground streams. It is controlled in its

development by a local base level which corresponds to the bed of a deeply entrenched master stream. All changes in the Karst cycle are related to the fluctuations of the local base level. The movement of water is controlled by the hydrostatic head, i.e., the pressure of water given to it by the difference in elevation between the point of entry and the lowest depths to which it reaches.

There are four main types of movement of the ground water seepage : (i) vertical downward movement, (ii) capillary rise through narrow pore spaces, (iii) turbulent flow through large openings, and (iv) percolation which is a slow movement through interconnected pores.

Karst topography develops very well where the following two essential conditions are fulfilled : (i) the soluble rocks are located near or at the earth's surface, and (ii) the rocks are dense, highly jointed, and thin-bedded. Two secondary conditions also favour the development. They are : (i) the presence of a deeply entrenched valley of a master stream, and (ii) a moderate amount of rainfall.

The basic process of acquiring material in the karst topography is solution or corrosion. Undissolved material is transported through suspension. This material causes corrosion. Dissolved material is transported through solution. The evaporation of the dissolved material leads to deposition.

There are two sets of features of the karst topography : those developed on the surface of the land and those below.

Features like Lapiés, solution pits, sink-holes, swallow holes, karst lakes, uvala, polje, karst valley and natural bridges, are

formed on the surface. Lapiés refer to the highly rugged surface occurring on considerable relief.

A Karst lake is formed by the lateral coalescence of sink holes. Its bed is covered by the impervious inwashed clay.

An uvala occurs on steep slopes. It is a very large elongated depression formed by the convergence of compound sink holes. A polje is a very large, deep and elongated depression. It is formed by the block movement of a limestone block between two parallel faults. A Karst valley is a very deep valley. It is formed by the solution process, and occurs in limestone rocks. A natural bridge represents the remnant of the roof of a natural tunnel or

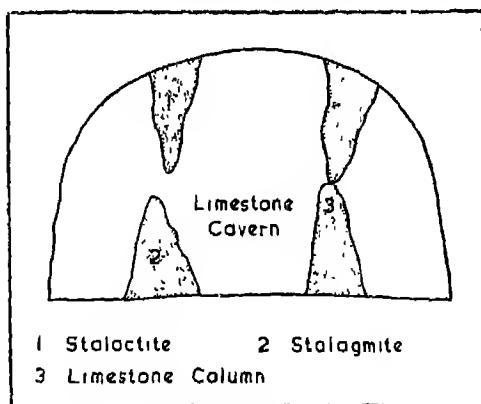


Fig. 95. Stalactite, Stalagmite and Limestone Column.

subterranean cut-off. Some characteristic underground or surface features occur in limestone caverns. These features include *stalactites* and *stalagmites*. Stalactites are formed by the slow evaporation of water containing dissolved limestone and dripping from the roof of the cavern. Stalactite is thus, a column that hangs from the ceiling downwards. Stalactites display a

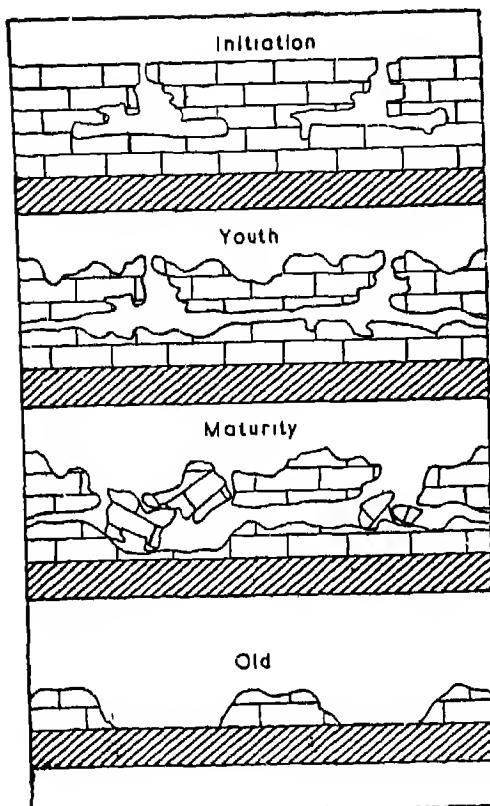


Fig. 96—The Cycle of Karst Erosion

large variety of forms. Stalagmites are the columnar features which rise up vertically from the floor of the cavern. When the stalactites and stalagmites join, they form a limestone column (Fig. 95).

*Karst Cycle*—There are four stages in the Karst cycle (Fig. 96). The *Youthful* stage has surface drainage and there is progressive expansion of the underground drainage. The mature stage displays lakes, uvalas, and caverns. Caverns reveal a multi-layered structure.

The *late maturity* stage is evidenced by a decline of the karst features. Cavern streams are now visible through karst windows. Arches, bridges, long gorges with streams, and polje lakes are characteristic features. The *old* stage reveals the reappearance of streams and deep entrenched valleys on the surface. By this time the entire mass of limestone would have been removed. Remnant hills and their associated features are characteristic of such a landscape.

### E X E R C I S E S

1. How does the hydrological cycle interconnect the lithosphere, the hydrosphere and the atmosphere?
2. What are the main components of the hydrological cycle?
3. Define evapotranspiration.
4. What are the factors which control the ground water table?
5. How are springs formed?
6. Describe the stages of the evolution of the Karst topography.

Books for further study

Strahler, A.N., *Physical Geography*, New York : John Wiley, 1960.

Trewartha, G., *An Introduction to Climate*, New York : McGraw Hill, 1954.





UNIT V

# Oceanography



## CHAPTER 21

# Ocean Basins and Submarine Relief

The relief of the sea or ocean floor is as complex and varied as the surface of the land. The furrows divide the oceans into elongated troughs and the transverse ridges subdivide these depressions into a series of basins which are separated from each other. The ridge and basin topography is the characteristic topography of the ocean bottoms.

### Ocean and Land

The significance of the oceans to physical and human geography is ultimately derived from its vastness. The oceans cover an area of about 361,059,000 sq. km. which is 71 per cent of the total area of the earth's surface. The distribution of the seas and oceans is highly irregular in different latitudinal belts, as well as in the Northern and Southern Hemispheres. Nearly 61 per cent of the area in the

former and 81 per cent in the latter are covered by water.

The overall distributional arrangement of the land and water on the globe is antipodal with the Arctic Ocean around the North Pole and the Antarctica Continent encircling the South Pole. Also, the great continental land masses of Europe, Asia and Africa are antipodal to the great oceanic areas of the South Pacific.

### Oceanic Water Bodies

There are three major oceanic water bodies : (i) the Pacific, (ii) the Atlantic, and (iii) the Indian. Together they constitute 90 per cent of the total area of water bodies. The Pacific is the largest ocean, both in surface area and volume. The main constituents of the hydrosphere are : oceans, inter-continental seas, smaller enclosed seas, and fringing seas

### Oceanic Relief Features

As one moves out from the edge of the land into water, one descends on to the continental shelf. This broad, shallow water zone containing canyons, submerged valleys, shelf bars, and areas of terrigenous deposits, is replaced seaward by the continental slope. The continental slope is a steeper zone that gives place to the continental rise which in its own turn is succeeded at far greater depths by the deep sea plain or abyssal plain. The abyssal plain contains ridges, hills, seamounts, guyots, deeps, and fracture zones. Numerous island arcs, atolls, coral reefs, submerged volcanoes, and seascarps create an enormous variety on the seabottom surface. Trenches and troughs abound on this surface. These divide the basins into smaller water bodies and the basins are separated by the ridges. The great variety of relief is largely due to the interaction of tectonic, volcanic, erosional, and depositional processes. At greater depths, tectonic and deep sea volcanism are signi-

fiant processes.

Ocean basins are some of the deepest relief features on the globe. The average depth of the sea is about 3800 metres. With the echo-sounding method, the depth of the sea at various locations have been measured. The extent and the proportion of the ocean floor at various depths are given in the following table :

Depth (metres)	Area (Million Km <sup>2</sup> )	Percentage (Globe area)
0—200	26	7.5
200—1000	18	4.5
1000—2000	13	4.4
2000—4000	69	29.5
4000—6000	207	53.0
above—6000	26	1.1

The table shows that as much as 82.5 per cent of the total oceanic area has a depth of 2000 to 6000 metres. The proportion of the oceanic area having a certain depth varies among the three major oceans. The proportions of the oceanic areas having

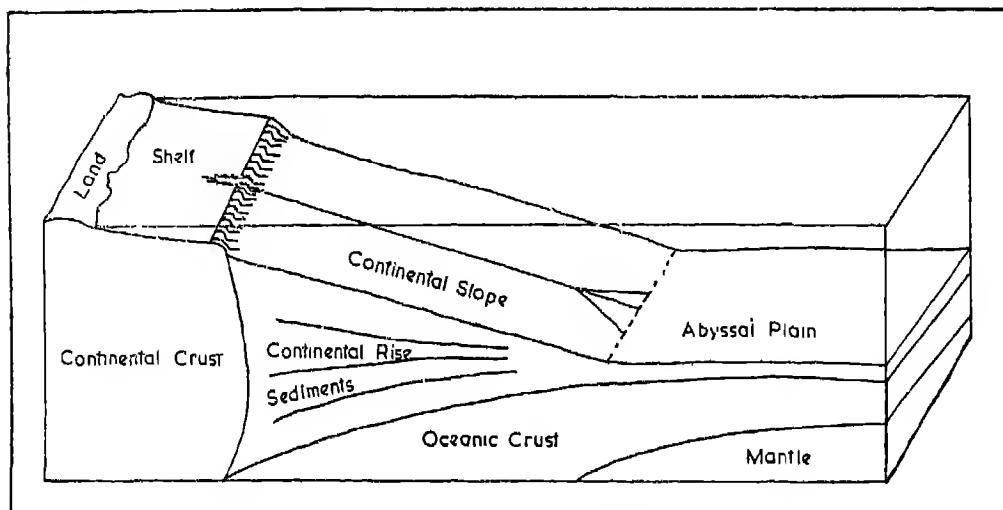


Fig. 97. Continental and Oceanic Crust

depths of more than 3000 metres are 65 per cent, 82 per cent, and 81 per cent, respectively, in the Atlantic, Pacific, and Indian oceans. According to depth, the oceanic bottom comprises of four zones : the *continental shelf*, the *continental slope*, the *deep sea plain*, and the *oceanic deep*. The continental shelf is the transition between the land and the actual sea bottom and is bounded on the seaward side by a depth of 200 metres (Fig. 97). The shelf covers an area of about 26 million square km, about 7·5 per cent of the global area. The continental slope has an average depth of 200 to 2000 metres but it covers a small proportion of the total oceanic surface, only about 8·5 per cent. The deep sea plain is located at a depth of 3000 to 6000 metres and covers about 77 per cent of the total oceanic area. The oceanic deeps are deeper than

the deep sea plains. They have depths of more than 6000 metres. Since they are linear features, they occupy small areas. They are more strikingly developed in the Pacific Ocean than anywhere else. Only about two per cent of the oceanic area is covered by the oceanic deeps.

#### *Submarine Ridges*

Submarine ridges are elongated high features on the floors of the oceans (Fig. 98). They may be 60,000 km long and 10 km high. The world-wide oceanic ridge system provides evidence of the global tectonics. Along the ridges there is the formation of a new ocean crust. It is also the line of sea-floor spreading. A large number of ridges are placed centrally in the oceans. At three places they run into the land, and at several places they meet or intersect. The most continuous ridge is the one which runs all across the

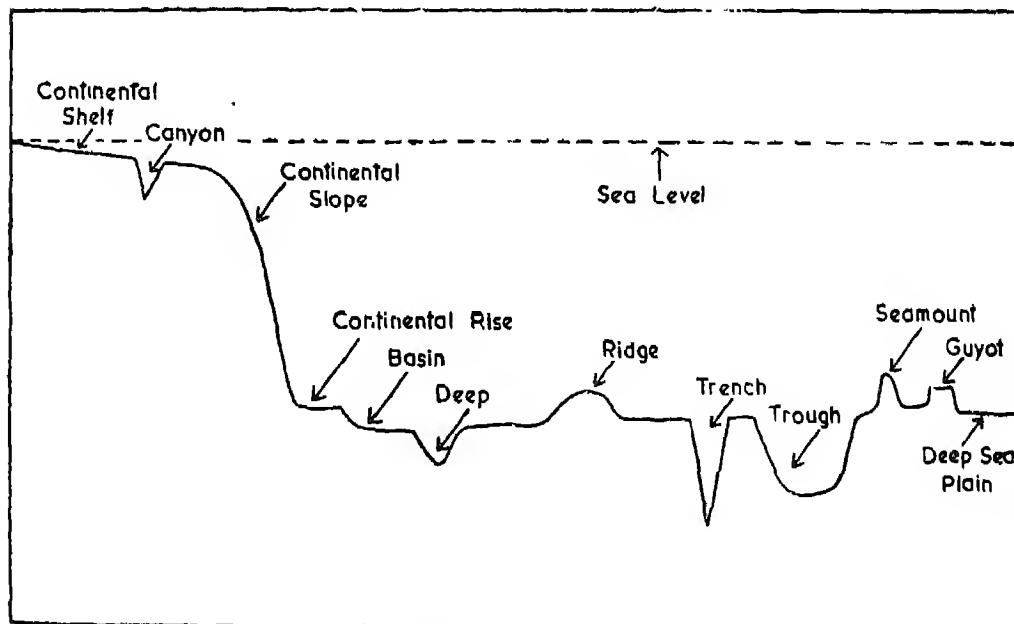


Fig. 98. Topographical Features of the Sea Bottom

Arctic Ocean. The ridges have been formed by various processes : (i) large outpourings of basalt along fissure lines, (ii) raising of the crust by the rising convection current, (iii) thickening and buckling of the basaltic crust by the downward movement of the convection current, and (iv) formation of new oceanic crusts. The ridges are either broad, gently sloping rises or steep-sided, narrow submarine mountains.

#### *Abyssal Plains*

An abyssal plain is located in the deeper parts of the ocean basin (Fig. 97). It is uniquely flat with a gradient of less than 1 : 1000. It is bounded by the hills on the seaward side. It occurs in small and large oceans and in all latitudes. The abyssal

plains are covered by sediments, both of terrigenous and shallow water origins. Most of the abyssal plains have been formed as a result of the burial of the original relief by turbidity currents. The largest abyssal plain of the Pacific occurs south of Alaska.

#### *Abyssal Hills*

The deep sea floor contains also abyssal hills, sea mounts, and guyots (Fig. 98). All these features are genetically related. The hills are formed by tectonic deformation and volcanism. Sea mounts and guyots are very common in the Pacific Ocean. The former have sharp and the latter flat tops. The features rise 3000 metres above the ocean floor. Both originated as volcanoes.

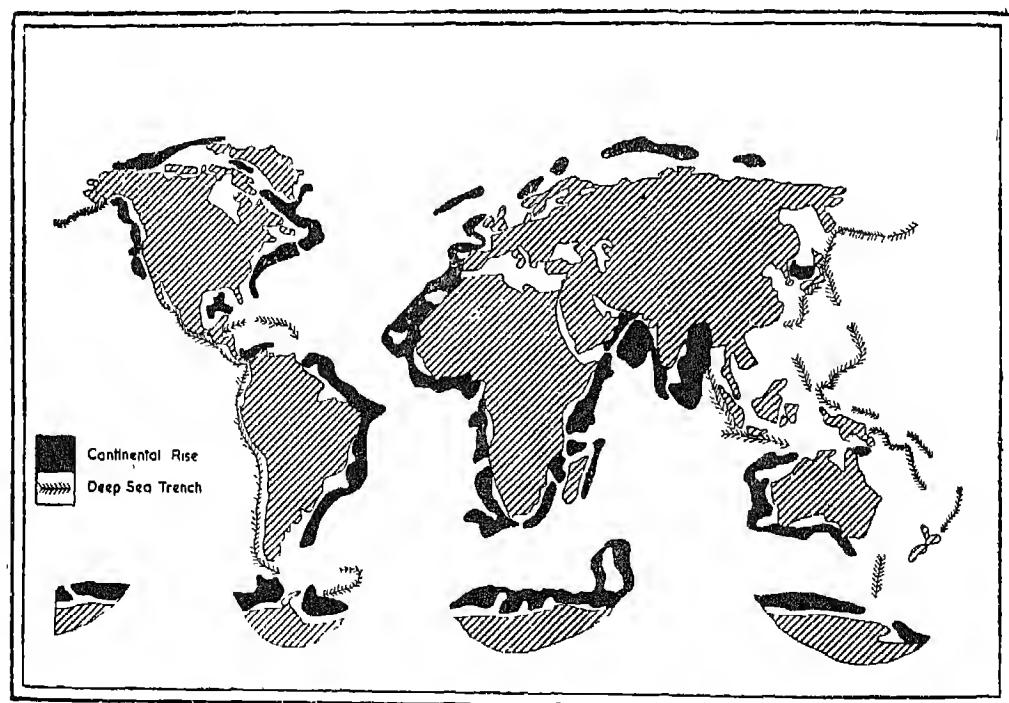


Fig. 99—Distribution of Continental Rises and Deep Sea Trenches

### Trenches

Trenches are deep—sea elongated depressions, mostly aligned with continental margins (Fig. 98). They are highly characteristic of the eastern and western margins of the Pacific Ocean where they form an almost continuous circum-Pacific ring. In the Atlantic, the trenches are located along the Antilles. Many of the trenches are associated with island arcs (Fig. 99). There are four types of trenches : peripheral type on the margins of the main oceans, marginal sea reversed trench marginal to the Pacific and parallel to island arcs, transverse or oblique trench which crosses oceanic ridges or continental structures, and those which extend parallel to the first and second types and forming the double arc system. The deeper trenches are more than 10,000 metres deep. The Mariana Trench in the Pacific is the deepest known with a depth of 11,022 metres. The trenches are only about 100 metres wide and more than 1000 km long. The trenches are the locales of the earthquake foci and associated volcanic activity.

### Basins

A basin is a large depression of a more or less circular or oval form (Fig. 98). A basin is a feature which is formed by crustal deformation. Both large and isolated basins are known. The basins are tectonically originated features and have a permanence that runs through long geological periods. The basins are related to global tectonics. Even the small, isolated basins are related to diastrophic events occurring in the adjacent larger basins. The oceanic floor is also undergoing tectonic changes and new ocean basins are being formed as a result of these changes.

A trough is a long, broad depression having

gently sloping sides as contrasted with a trench which has very steep sides. The troughs are bordered by contrasted and longitudinal ridges. They are far more characteristic of the Pacific Ocean. The troughs are very deep, exceeding 8,000 metres. In the Arctic Ocean, the troughs cut across the continental shelf. Elongated troughs are common in the Atlantic Ocean where they are separated from each other by ridges.

Toward the sea, from the coastal zone, extends the continental marginal zone. This covers about 50 per cent of the area occupied by the land and 21 percent of the total ocean area. The continental shelves, the continental slope, and the continental rise occupy 27, 28 and 19 million square km of the area respectively.

### Continental Shelf

The continental shelf joins the continental slope to the land. It is a belt of shallow water and is mostly covered by sediment. The average width is about 70 km and the mean slope is less than one degree. Glaciated shelf, shelf off a large river, shelf with dendritic valleys, coral reef shelf, and shelf along young mountain ranges are the various types of shelves.

The continental shelves cover about 7.5 percent of the total area of the oceans and 18 percent of the land. Some shelves are underlain by the sedimentary strata, while others by the igneous and metamorphic strata. The shelves have widened the continents by up to 800 km through the deposition of about 2 km thick sediment. The rise and the fall of the sea level during the last 15,000 years have changed the surface character of the shelves very much. Barrier beaches, rock dams, and drowned glacial deposits are related to

these processes. Old beaches and moraines can also be identified on the shelves. The shelves are of great use to man. Marine food comes almost entirely from them. About 20 percent of the world production of oil and gas comes from them. They are also large stores of sand and gravel. Finally, the shelves are the sites of productive fishing grounds.

#### *Continental Slope*

The continental slope joins the shelf to the deep ocean floor (Fig. 97). The average gradient of the slope is about four degrees. On the slopes are the best developed submarine canyons. One of the best known slopes is located off West Florida in the U.S.A. There are five types of slopes : fairly steep with the surface dissected by canyons, gentle slope with elongated hills and basins, faulted slopes, slopes with terraces, and slopes with sea mounts.

#### *Continental Rise*

The continental rise is a prism of thickened sediments located below the surface of the continental slope. At places it is 1.6 km thick (Fig. 97). The rise has a slope of 1° to 6°. The material of the rise has been derived from the shelf and slope. The rise is a major zone of deposition on the continental margins during recent geological time (Fig. 99). On the lower parts of some of the rises are belts of hills adjacent to the abyssal plain. Most of the rise surface contains deposits brought by turbidity currents. The continental rises are found only where the continental margins lie within the crustal plates. Of the total area covered by the continental margins, as much as 19 million square km is accounted for by the continental rises. All the continental rises are separated from the shelf by the continental slope.

#### *Bank, Shoal and Reef*

Bank, shoal and reef are the marine features which are formed through the processes of erosion, deposition, and biological activity. They are produced upon features which may primarily be of diastrophic origin and are located on the upper parts of elevations which show the effects of erosion or deposition.

A bank is a more or less flat topped elevation located in the continental margins. The depth of water over a bank is relatively small but is adequate for navigation. The Dogger Bank in the North Sea and the Grand Bank in the North-Western Atlantic off Newfoundland, are famous examples. At places, as in the Grand Bank, the banks are formed by the many hills of the outer shelf rising nearly to sea level. During the Pleistocene Ice ages when there was a fall in sea level, the surfaces of the banks were glacially eroded : for example, the George's Bank off the eastern coast of the U.S.A. On the other hand, the Dogger Bank constitutes the remains of a glacial moraine. The offshore banks are almost everywhere modified by tidal streams. In some banks, as in the Bahama Banks in the West Indies waters, there are enormous wedges of sediments. The banks are the sites of some of the most productive oceanic fisheries of the world.

A shoal is a detached elevation with such shallow depths that it is a danger to surface navigation. The shoal is not composed of a rock or coral. At many places shoals are associated with banks. In the Dogger Banks are shoals which are about 18 metres above their surroundings and only about 20 metres below the water surface at their crests.

A reef is a rocky or coral elevation

having a generally elongated shape. It is dangerous to surface navigation because it may extend above the surface. There are many well-known types of reefs : fringing reef, barrier reef, coral reef and atoll reef. The most widespread are the reefs associated with atolls and formed by the coral organism. The largest barrier reef extends off the Queensland coast of Australia. In its formation it is related to faulting of a peneplain and the activity of reef-building organisms. Within the reefs are flat and shallow areas filled with sediments. The reef is generally 190 km long and 160 km wide toward the south. The reef spreads over a platform and is quite linear in pattern. The coral reefs are most characteristic of the Pacific Ocean where they are associated with seamounts and guyots. Although reefs are morphological features, all of them are related to the highly productive biological activity of the corals.

#### *Submarine Canyons*

Submarine canyons have been known for a long time as one of the intriguing morphological features on the continental shelf and slope. These features occur around all the coasts of the world. The submarine canyons are strikingly deep valleys which have cut the plain sharply. Many canyons are associated with the mouths of large rivers, such as Hudson, Mississippi, the Yukon, Indus, Ganga, Congo and Columbia.

Broadly, there are three types of canyons : (i) small gorges which begin at the edge of the continental shelf and extend down the slope to very great depths, (ii) those which begin at the mouth of a river and extend over the shelf, and (iii) those which have a dendritic appearance, and deeply cut into the edge of the shelf and the

slope. The examples of these three types, respectively, are the Oceanographer Canyon in New England shelf, the Congo, the Mississippi, and the Indus Canyons, and canyons off the coast of southern California.

Echo-sounding, sampling of the geological cores, remote photography, current measurements, etc., scuba diving provide data for the study of these submarine canyons.

The largest canyons in the world occur in the Bering Sea off Alaska. They are the Bering, Pribilof, and Zhemchug canyons. The Bering is about 400 km. long and has a volume of 4300 cubic km, while the Zhemchug has a volume of 8500 cubic km. It has a depth of 2600 metres.

It has been suggested that the submarine canyons owe their origin to subaerial processes and submarine processes. During the Pleistocene period, sea level went up and down to the extent of 100 metres. When it went down, the shelf was exposed to the river action and other subaerial processes. Similar effects were produced when faulting pushed a part of the shelf up. On the other hand, marine processes explain the canyons which extend to great depths.

It is quite possible that the canyons are the valleys which have been cut by rivers and have been, later on, down-faulted to their existing positions. This process is supported by the presence of hard rocks on the walls of the canyons. Along some coasts the continental margins have suffered fracture or bending which has submerged the river-cut valleys to become the submarine canyons.

The other process is the operation of turbidity currents. Water containing sediments has a higher density than clear

water. Hence, being heavier, it will flow down the slope, erode, and will collect more sediments. Such a self-generating current is termed *turbidity current*. Erosion by turbidity currents along the edge of the shelf results in the formation of the submarine canyons.

### The Three Oceans

Generally speaking, there oceans are recognised : the Pacific, the Atlantic, and the Indian.

### *The Pacific Ocean*

The Pacific Ocean covers about 30 per cent of the earth surface. Its average depth is about 5,000 metres. On the north, it is blocked from the Arctic Ocean by the Bering Sea. The Pacific Ocean has more than 20,000 islands comprising volcanic, low coral, island arcs, and continental types. Many marginal seas, bays, and gulfs occur along its

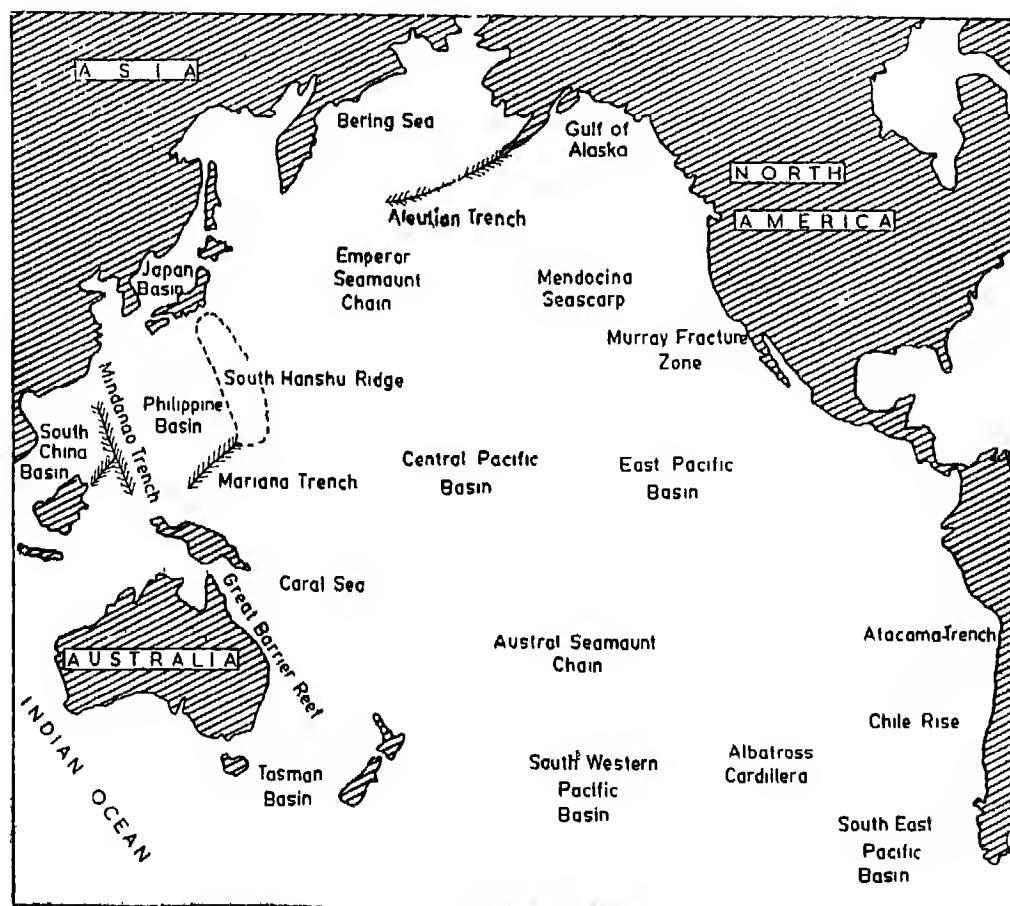


Fig. 100. Pacific Ocean Basin Bed Topography

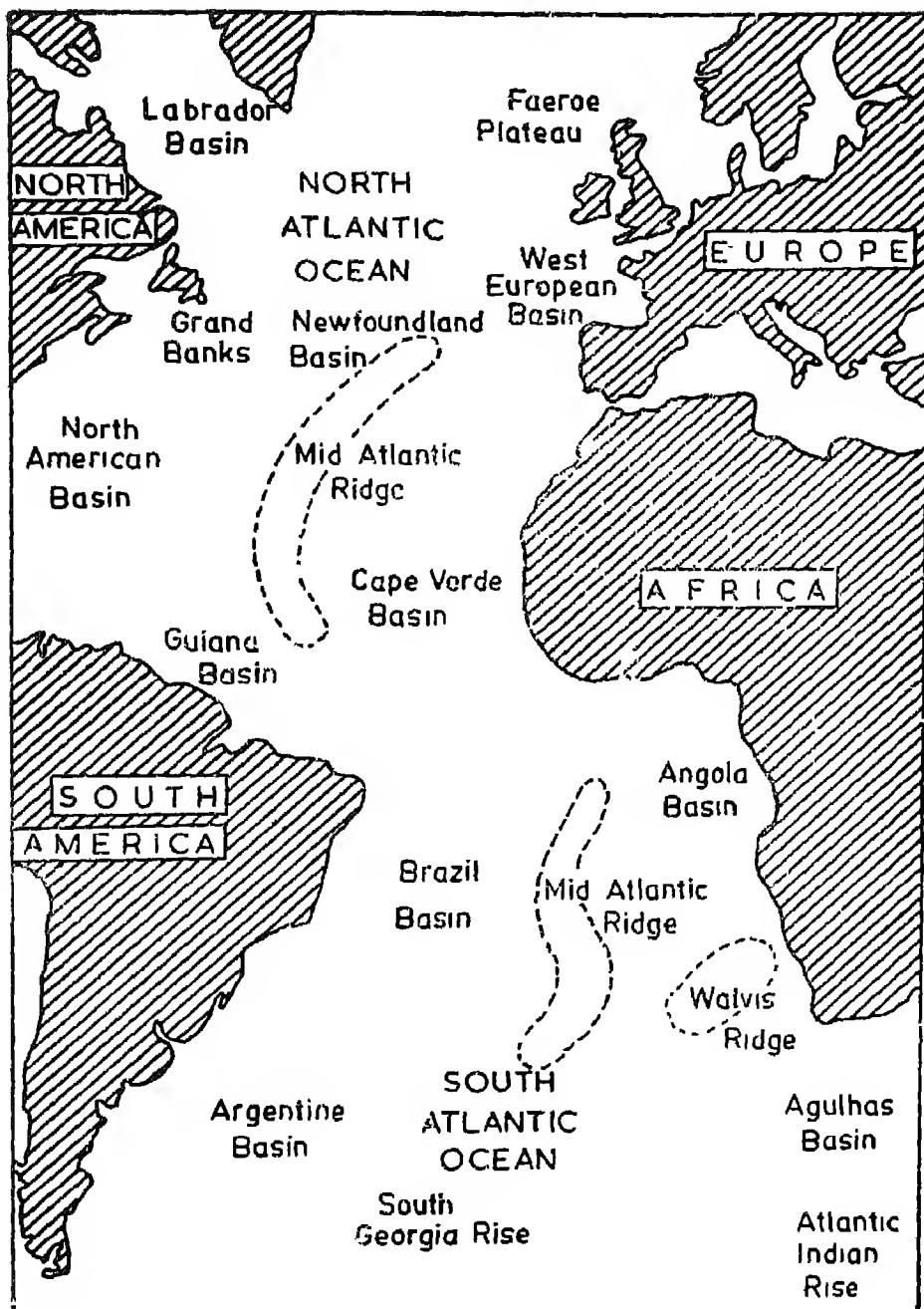


Fig. 101. Atlantic Ocean Basin Bed Topography

boundaries. The Northern Pacific is the deepest part of the Ocean basin and has a large number of deep trenches and island arcs. Aleutian, Kurile, Japan and Bonin are the well-known trenches of this basin, ranging in depth from 7000 to 10,000 metres. The Central Pacific is full of islands, most of which are coral and volcanic in origin. There are a large number of sea-mounts and guyots and parallel and arcuate island chains. The South-West Pacific is about 4000 metres deep and has a variety of islands, marginal seas, continental shelf, and submarine trenches. The Mindanao Trench is more than 10,000 metres deep. The South-East Pacific contains the Tonga and Atacama trenches which are about 9000 and 8000 metres deep respectively (Fig. 100).

The continental shelf is more characteristic of the western margins of the Pacific, while its eastern shores have narrower shelves backed by the high mountains of Rockies and Andes. There is now a central ridge in the Pacific Ocean but there are quite a few swells, plateau, fracture zones, sea-scarp, cordillera and coral and barrier reefs.

#### *The Atlantic Ocean*

The Atlantic Ocean covers an area of 82 million sq. km which is about half the area of the Pacific Ocean. The most striking topographic feature of this ocean is the mid-Atlantic Ridge. (Fig. 101). It extends from the north to the south, paralleling the 'S' shape of the ocean itself and divides it into Western Atlantic and eastern Atlantic parts. The ridge is about 14,000 km long and about 4,000 metres high. It is a broad, fractured feature. It rises as a series of steps and becomes

rugged near the crest. On the crest there is a rift valley.

Within the Atlantic Ocean there are several smaller basins. Adjacent to the Atlantic are the Caribbean Sea, the Gulf of Mexico, the Mediterranean Sea, the Baltic Sea, and the North Sea. North Cayman and Puerto Rico are the two troughs and Romanche and South Sandwich are the two trenches in the Atlantic Ocean. By and large the Atlantic Ocean lacks in troughs and trenches which are far more characteristic of the Pacific Ocean. On the other hand, continental shelves occur all around the Atlantic Ocean. They vary in depth at places. Off the coast of Africa, they are 80 to 160 km wide but off the coasts of North-East America and North-West Europe, they are 250 to 400 km wide. Most of the marginal seas are located on the shelves. The Hudson Bay, the Baltic Sea, the North Sea, and the Straits of Denmark and Davis are located on the shelves.

#### *The Indian Ocean*

The Indian Ocean is bounded on three sides by Africa, Asia and Australia. It has an average depth of 4000 metres. There is a large variety of islands, volcanic cones, submarine ridges, submerged folded mountains, and coral in origin. There are a large number of ridges and basins. The most important divide is the Mid-Indian Ridge which runs along 75°E meridian (Fig. 102). The ridge starts from the Maldives and Laccadives islands and extends south upto 45°S parallel. The Mid-Indian Ridges paralleled on the east and west by East Indian and West Indian ridges. West of the Mid-Indian Ridge are the two large

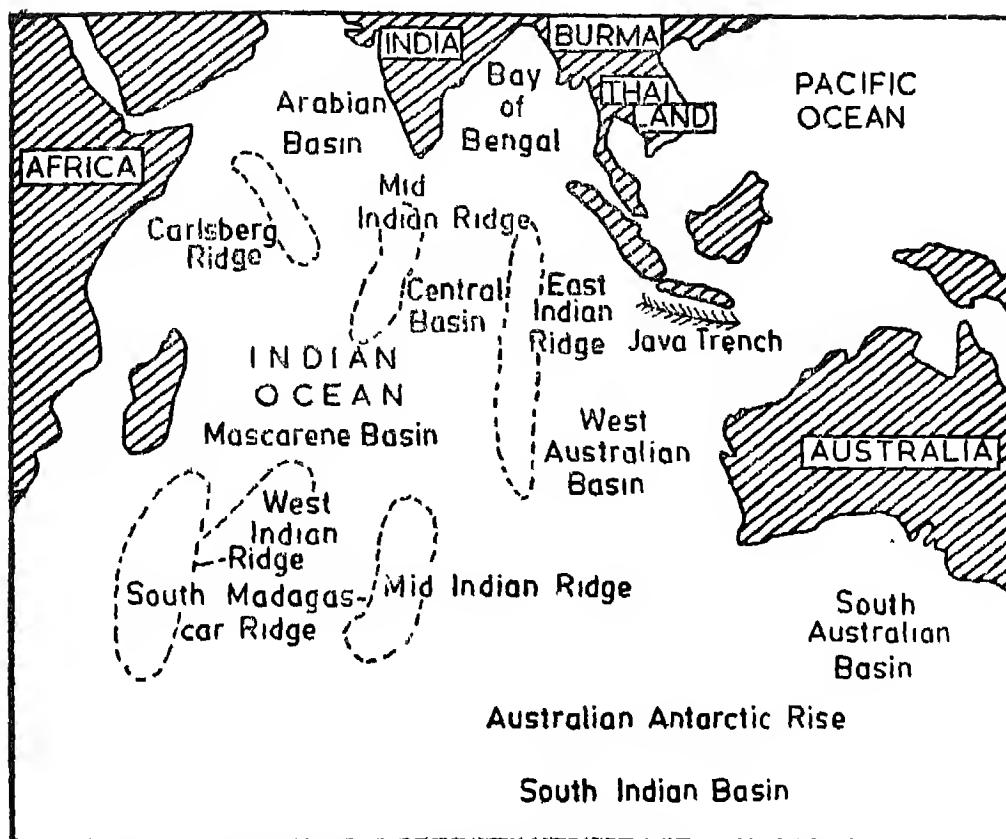


Fig. 102. Indian Ocean Basin Bed Topography

basins, Arabian in the north and Mascarene in the south. The smaller ridges shooting off from the main ridge to its west are Carlsberg, Seychelles, Mauritius, South Madagascar and Atlantic-Indian.

To the east are the Bay of Bengal, Central Basin, West Australian, South Australian and South Indian basins. The Sunda trench located south of Java is one of the few deeps in the Indian Ocean.

### EXERCISES

1. Name the most common features of the oceanic land.
2. How have deep-sea ridges been formed?

3. Explain the characteristics and formation of submarine canyons.
4. Describe the salient features of the topography of the Atlantic Ocean.
5. Name the topographic features which are common to all the three oceans : the Atlantic, the Pacific and the Indian.

#### **Books for further study**

- Gulcher, A., *Coastal and Submarine Geology*, New York : J. Wiley, 1958.
- Shepard, F.P., *Submarine Geology*, New York : Harper & Bros, 1948.
- King, C.A.M., *Beaches and Coasts*, London : Edwin Arnold, 1959.
- Small, R.J., *The Study of Landforms*, Cambridge : Cambridge University Press, 1972.



## Ocean Waters and Their Circulation

The temperature of the oceanic waters plays a significant role in the movement of large masses of the ocean waters, their attributes and the types and distribution of organisms at various depths.

There are two main processes of the heating of the oceanic waters : absorption of radiation from the sun and convection. There are three principal processes of cooling : back radiation of heat from the sea surface, convection and evaporation. The interplay of heating and cooling results in the characteristics of temperature.

The distribution of temperature is determined by the following factors : the intensity and daily duration of solar radiation, the loss of insolation in the atmosphere, the amount reflected from the surface, salinity, density and atmospheric pressure, the heat balance between the heat received

and the heat transmitted back, heat transfer through evaporation and condensation, invasion of warm or cold currents or winds, local weather conditions, the location of submarine ridges, and the location and shape of the sea.

### Diurnal Range of Temperature

The diurnal range of temperature, like the annual range of temperature, is controlled by the balance between the insolation and back radiation. The daily march of temperature does not strictly follow the march of daily insolation and is affected by cloudiness, stability of air, and nature of the sea surface. In the open seas, the diurnal range of temperature is small, about one degree only. The maximum temperature occurs at about 2 P.M., and the minimum at about 5 A.M. The sea is an enormous body of water. The specific heat of water

is high. Hence, a much larger amount of heat is needed by the sea to raise its temperature than the land. The sea water does not experience large diurnal ranges of temperature.

### **Annual Range of Temperature**

The annual variation of the temperature of the sea surface is also small, only about  $1^{\circ}$  to  $8^{\circ}\text{C}$ . The smaller, partly enclosed seas display a higher range. The Mediterranean and the Baltic Sea reveal the ranges of about  $7^{\circ}$  and  $14^{\circ}\text{C}$  respectively. The annual range on the sea surface is high in the lower latitudes, the coastal areas, the enclosed seas, and the areas which experience two different types of water masses within a year. The annual variation is controlled by four factors : (i) variations in heat at different depths, (ii) the effect of heat conduction, (iii) the effect of convectional currents, and (iv) the lateral displacement of water masses.

### **Surface Temperature**

The sea surface temperature is mainly controlled by latitude. Hence, the sea surface isotherms are generally parallel to parallels of latitude. The temperature decreases with the distance from the equator. In the Atlantic Ocean, temperatures near the equator and at  $70^{\circ}\text{N}$  latitude are  $26^{\circ}$  and  $5^{\circ}\text{C}$ , respectively. The highest values of the surface temperature in the oceans, in general, occur to the north of the equator. The latitudinal decrease is influenced a good deal by the presence of warm and cold ocean currents. Because of the warm Gulf Stream, the surface temperature of the eastern part of the North Atlantic in higher latitudes is more than  $5^{\circ}\text{C}$ , while in other parts in the same latitudes it is only  $2^{\circ}\text{C}$ .

### **Distribution of Annual Temperatures**

Annual temperatures of the sea surfaces can be studied under the January and July conditions which represent the warm and cold extremes or the summer and winter seasons.

#### *January*

In January (Fig. 63) for all the oceans, temperatures are the highest, about  $21^{\circ}$  to  $32^{\circ}\text{C}$ , in a latitudinal zone which extends from  $25^{\circ}\text{N}$  to  $40^{\circ}\text{S}$ . There is a far greater extent of high temperatures in the Southern than in the Northern Hemisphere. Within this zone, temperatures of  $26^{\circ}\text{C}$  to  $32^{\circ}\text{C}$  occur between  $10^{\circ}\text{N}$  and the Tropic of Capricorn. The lowest temperatures of  $-45^{\circ}\text{C}$  occur in the polar areas of the Northern Hemisphere. The gradient of decrease in the Northern Hemisphere is steeper than in the Southern counterpart. In the Southern Hemisphere, the lowest temperatures are only about  $-1^{\circ}\text{C}$  to  $10^{\circ}\text{C}$ , which means that the higher latitudes of the Southern Hemisphere are far warmer than those of the Northern. In the Northern Hemisphere, the isotherms are more or less parallel to the equator. In the Southern Hemisphere, they are bent toward the equator near the tropical areas, but in the higher latitudes they are parallel to the parallels of latitudes. The configuration of the isotherms is controlled by the presence of warm and cold ocean currents, shape of the oceans, shape of the continents, and the distributional pattern of the oceans and continents. Easily, the most important of these factors is the ocean currents.

#### *July*

In July (Fig. 64), the latitudinal belt of

the highest temperature of  $20^{\circ}$  to  $32^{\circ}\text{C}$  extends from about the Tropic of Capricorn to about  $40^{\circ}\text{N}$  latitude. The highest temperature of more than  $32^{\circ}\text{C}$  occurs in the Red Sea. In the Northern Hemisphere, the isotherms are more irregular than in the Southern and are bent toward the north pole. In the Southern Hemisphere, the isotherms are generally parallel to the parallels of latitudes, as is observed for winter conditions. Here, the isotherms have more or less an equal spacing revealing a uniform gradient, but steeper than in the Northern Hemisphere. The minimum temperature of  $-1.1^{\circ}\text{C}$  occurs in the southern parts of the Atlantic and the Indian Ocean along the parallel of  $60^{\circ}\text{S}$  latitude. In the Northern Hemisphere, the minimum temperature of about  $4^{\circ}\text{C}$  occurs north of the Arctic Circle. Along the north-western coast of Europe and south-western coast of Africa, the isotherms bend toward the pole and toward the equator, respectively. This is related to the Benguela cold and the Gulf Stream warm current.

### **Thermal Anomalies**

The difference between the average temperature of a place and the average temperature of the parallel on which it is located is called the *thermal anomaly*. The lines joining the places having the same anomaly values are termed *is anomals*. The anomaly is mostly due to the presence of the cold and warm currents. There are two types of anomalies : *positive* and *negative*. The positive anomaly is related to warm currents and the negative to cold currents.

### **Subsurface Temperatures**

The surface of the sea water receives the largest amount of insolation. As the

rays penetrate the water, their strength is reduced by scattering, reflection, and diffusion. Hence, there is a decrease in the temperature with the increasing depth. Up to a depth of about 100 metres, the temperature of water is about the same as that of the surface. The rate of decrease in the temperature is not equal at all depths. While it falls from about  $15^{\circ}\text{C}$  to about  $2^{\circ}\text{C}$  between the surface and a depth of 1800 metres, the decrease between 1800 and 4000 metres is from  $2^{\circ}\text{C}$  to about  $1.6^{\circ}\text{C}$ . The rate of decrease is not the same at the equator and the poles. At the equator, it is greater than at the poles. Upwelling of water, sinking of dense surface water, regional higher insolation, and submarine barriers influence variations in the sub-surface temperature. Of these, the most important factors are the cold and warm currents and the submarine topography.

### **Salinity**

The oceanic water contains a large number of dissolved salts. These salts result in the property of salinity. The average salinity of the oceanic water is about 35 per thousand which means that in 1000 grams of this water there are 35 grams of salts. The value is smaller where large rivers meet the sea, but very high in the closed seas, such as the Red Sea.

Salinity determines, among other features, compressibility, thermal expansion, temperature, density, absorption of insolation, evaporation, and humidity. The amount of salinity also greatly influences the composition and movement of the ocean waters, the distribution of sea fish, sea animals and plankton. The salts in the oceanic waters are ultimately derived from the earth's crust. Sea waves and rivers

erode the crustal rocks and dissolve their constituents and add them to the oceanic waters.

### Distribution of Salinity

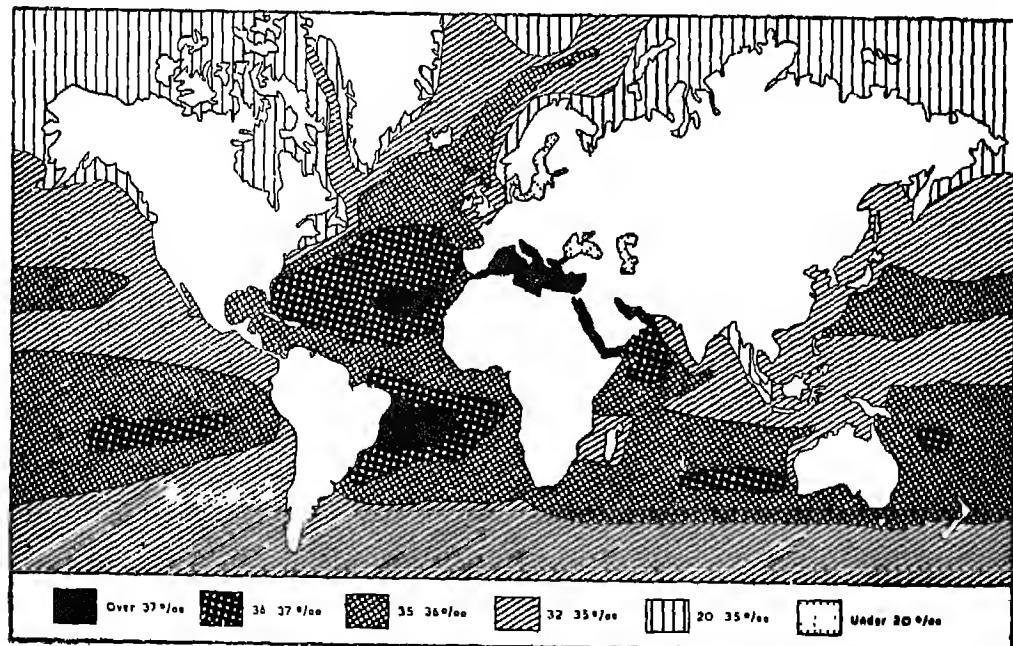
The distribution of salinity has two aspects : (i) horizontal, and (ii) vertical.

The amount of salinity varies in different areas of the oceans. These variations are controlled by evaporation, precipitation, river water, atmospheric pressure and wind direction, and movement of the sea water.

Broadly, the strength of these factors decreases from the equator toward the poles. Hence salinity also decreases in the same direction. The maximum salinity occurs between  $20^{\circ}\text{N}$  and  $40^{\circ}\text{N}$  and  $10^{\circ}\text{S}$  and  $30^{\circ}\text{S}$ . Here, salinity is 36 per thousand. Near the equator, the

rainfall is much higher than evaporation, hence salinity is low. In the lower middle latitudes, salinity decreases between  $40^{\circ}\text{N}$  and  $60^{\circ}\text{N}$  and  $40^{\circ}\text{S}$  and  $60^{\circ}\text{S}$ . In the polar areas, salinity is low because of the addition of water by the melting of the ice. There is little difference in the amounts of salinity in the Northern and Southern Hemispheres. The slightly higher value (35 per thousand) of the Southern Hemisphere is due to the abundance of the ocean waters. (Fig. 102 and 103.)

Along the coasts, salinity is lowered by the addition of fresh water. In the open seas, the ocean currents, precipitation and evaporation account for the differences in salinity. Partly enclosed seas in the middle latitudes have a very high salinity because of large evaporation. The North Sea has



Adapted from D.M. Preese and H.R.B. Wood

Fig. 103. Distribution of Salinity

higher salinity than the Baltic Sea because the addition of fresh water in the former is less.

### Regional Distribution

The regional distribution of salinity refers to the salinity patterns of the oceans : the Atlantic, the Indian, the Pacific, and the Indian seas and lakes.

The average salinity of the Atlantic Ocean is about 36 per thousand. The latitudinal variations in the amount of salinity in this ocean and those of the oceanic waters in general are practically similar. In the higher latitudes, saline waters are brought by the Gulf Stream warm current to the eastern parts of the North Atlantic. Along the coasts of Gulf of Guinea (West Africa) cold water up-wells and reduces salinity. In the western parts of the higher latitudes, salinity is low. In the Mediterranean Sea, evaporation is greater and, hence, salinity is high ; in its eastern parts, salinity is 39 per thousand.

In the Indian Ocean, salinity is low (35 per thousand between  $0^{\circ}$  and  $10^{\circ}\text{N}$ ). It is low in the Bay of Bengal and relatively higher in the Arabian Sea. In the southern part, maximum salinity occurs in waters west of Australia due to the tropical dry climate conditions. The Red Sea and the Persian Gulf have high salinity. In the inner parts of the Red Sea, salinity is as high as 40 per thousand.

In the Pacific Ocean, maximum salinity of 35 per thousand occurs between  $15^{\circ}$  and  $30^{\circ}$  latitudes, north and south of the equator. In the higher latitudes in the western parts, salinity is reduced by the addition of fresh water from the melting ice and cold currents and by the disappearance of the warm Kuroshio current. Similarly, lower salinity occurs in the lower lati-

tudes in the eastern parts where it is due to cold currents.

Salinity in the inland seas and lakes is generally high because evaporation is higher than precipitation. The salinity values of the Great Salt Lake in Utah and the Red Sea are 220 per thousand and 240 per thousand respectively.

### Sub-surface Salinity

In general, salinity decreases with the increasing depth. This decrease varies greatly with latitude. But the decrease is also influenced by cold and warm currents. The rate of decrease is highly variable in the North and South Atlantic Oceans. In high latitudes, salinity increases with depth. In the middle latitudes, it increases up to about 35 metres and then decreases. At the equator, the surface salinity is lower.

### Movements in the Oceanic Waters

The ocean water experiences three types of movements : waves, currents and tides.

#### Waves

The ocean waves are the oscillating motion of the sea surface. This is indicated by the rise and fall of the level of water. The waves are formed by the friction of the wind against the surface of water (Fig. 104). Once the surface is disturbed and its form is changed, there is a push against the rear, suction over the crest, pull at its front, and vertical compression in the trough (Fig. 104.) There four processes of the wind creat the wave which is more a form of the water surface than movement. There is negligible forward movement of the water.

Every wave has a wave length, wave velocity and wave period. Wave length is the distance between two adjacent

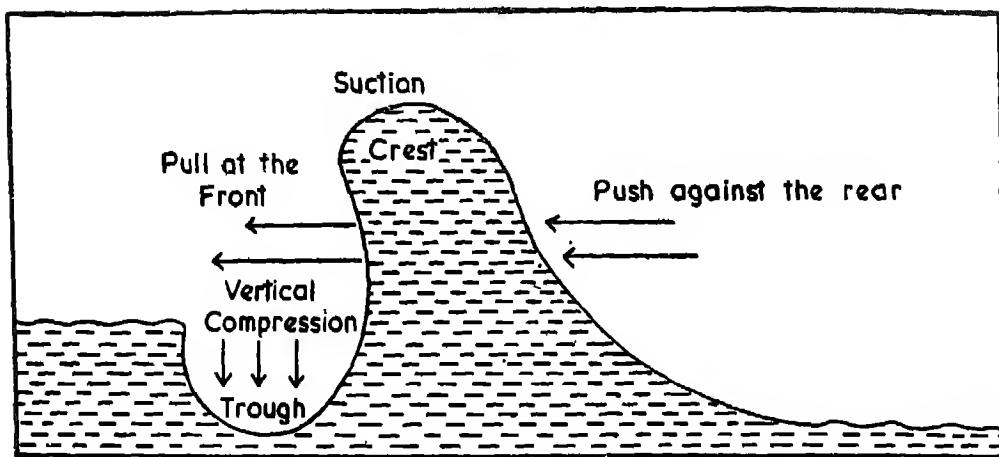


Fig. 104. Formation of Wave

crests or troughs. It is influenced by the depth of the water, the velocity of the wind, the duration of the wind, and the bottom topography. Where the water is deep, the winds are fast, the winds blow over a long period, and the bottom does not interfere with the undulatory movement of the water, the formation of waves is unrestricted and full. Wave weight is the weight of the crest from the base

(Fig. 105). The maximum wave height is about 16 metres. The waves are higher where the winds blow over a long period, the wind velocity is high, and the extent (fetch) of the water over which the wave form advances. Wave period is the time taken by two consecutive crests to pass any reference point. In Fig. 106 the wave velocity is 100 metres per half an hour and the wave period is half an hour.

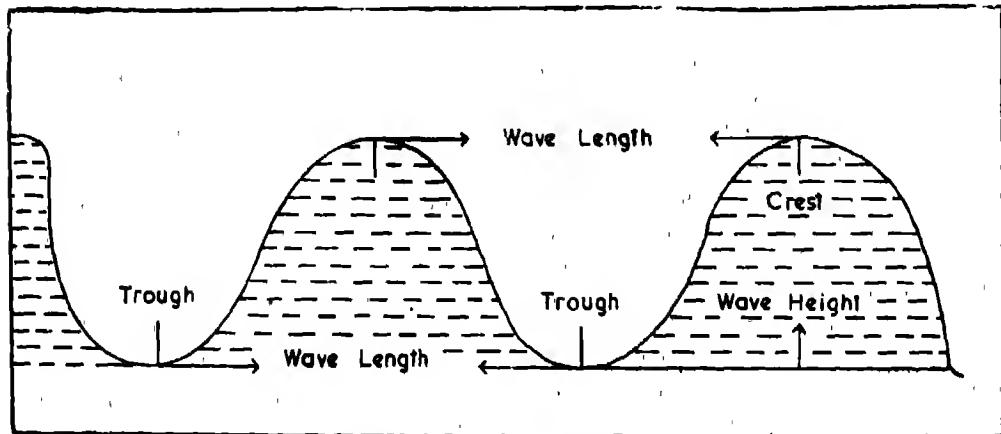


Fig. 105. Wave attributes

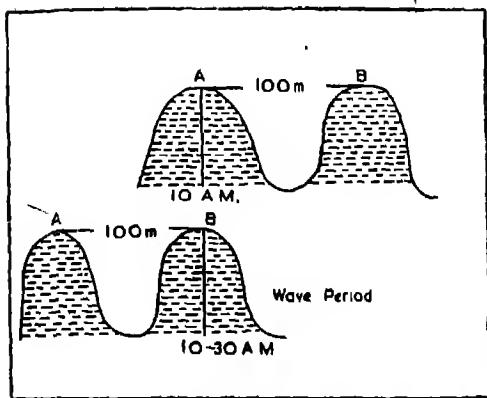


Fig. 106. Wave Velocity

There are two types of waves : (i) the wave of oscillation or the transverse wave, and (ii) the wave of translation or the longitudinal wave. The transverse wave develops in deep water. It has a free orbital movement. The circular movement of water particles is actually their oscillation which is transverse to the direction of the wave movement. Movements are forward on the crest, upward on the front, backward in the trough,

and downward at the back (Fig. 107). There is a slow but small movement of water in the direction of the wave movements. The movement on the crest is more rapid than in the trough. Also, the mass movement of water is larger in high than in low waves.

In the longitudinal waves when the water moves forward, there is no compensatory backward motion. The particles move in the direction of the waves. It is a single wave. On the surface, the movement of the particles is parabolic and at the bottom it is in straight lines. Longitudinal waves are formed from transverse waves when they break in shallow water. In shallow water, the orbital velocity decreases. Along with it decreases the wave height. There is lack of water at the base. A curl is formed at the crest. When the curl breaks, it changes to surf. This is also termed the swash or the wave of translation. The return movement to the sea is

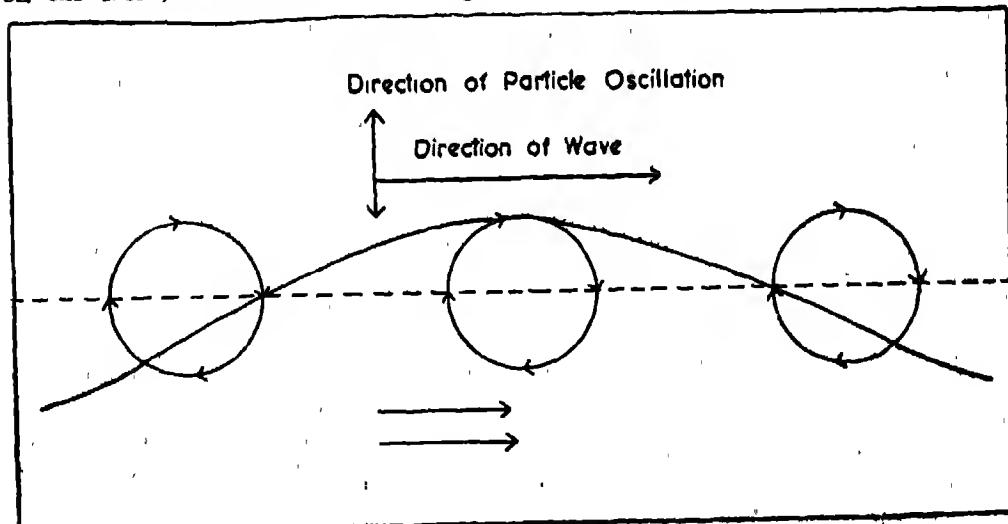


Fig. 107. Transverse Wave

termed the *backwash*.

Work done by different waves and their constituent movements is of different kind. Longitudinal waves move material forward on the sea bottom, and, thus, they do a large amount of geologic work. Swash or uprush or surf moves the sand and gravel toward the land on the beach. The backwash sweeps the sand and gravel toward the sea. The transverse waves set up oscillations which damage jointed structures. The resulting alternating increase and decrease of pressure pull away jointed blocks.

#### Currents

In terms of their significance, both in physical and human geography, the ocean currents are the most important of the movements in the oceanic waters. Unlike the waves in which there is a change merely of the shape of the water surface, in the currents there is an actual movement of the water over great distances. The oceanic currents are initially classified into surface and sub-surface currents.

The oceanic currents can be classified on the basis of their origin and temperature. According to their origin, the ocean currents are of three types : (i) longshore or littoral currents, (ii) undertow currents, and (iii) rip currents. Longshore currents are produced by two processes : (i) when the waves break obliquely against the shore and change into longshore currents, and (ii) when after impinging on the shore, they change their direction. In both the cases, the currents begin to move parallel to the shore. When sand is moved parallel to the shore, it is termed *longshore drifting*. Undertow currents are the seaward movements of the water.

Rip currents are localised streaks of seaward returning water.

Warm and cold currents are more well known in geography. The origin and nature of the movement of these currents are related to four sets of factors (i) factors related to the earth's rotation : gravitational force and force of deflection, (ii) factors originating outside the sea : atmospheric pressure, winds, precipitation, evaporation and insolation ; (iii) factors originating within the sea : pressure gradient, temperature difference, salinity, density, melting of ice, (iv) factors modifying the ocean currents : direction and shape of the coast, seasonal variations and bottom topography.

As a result of the interplay of these factors, the currents reveal the following characteristics. In the Northern Hemisphere, the currents move to their right and in the Southern, to their left. This is due to the effect of the Coriolis force or deflective force and follow Ferrell's law. Warm currents move toward the cold seas and cool currents toward the warm oceans. Cold dense waters near the surface occur in the middle latitudes on the western shores of the continents. Cold waters of lesser density move into the warmer oceans along the eastern coasts of higher latitudes. In the lower latitudes, warm currents flow on the eastern shores and cold on the western shores. In the higher latitudes, warm currents move along the western shores and cold currents along the eastern shores. Convergences along which the warm and cold waters meet and divergences from which they move out in different directions also control the currents.

#### Surface Currents of the Oceans

The world pattern of the ocean currents |

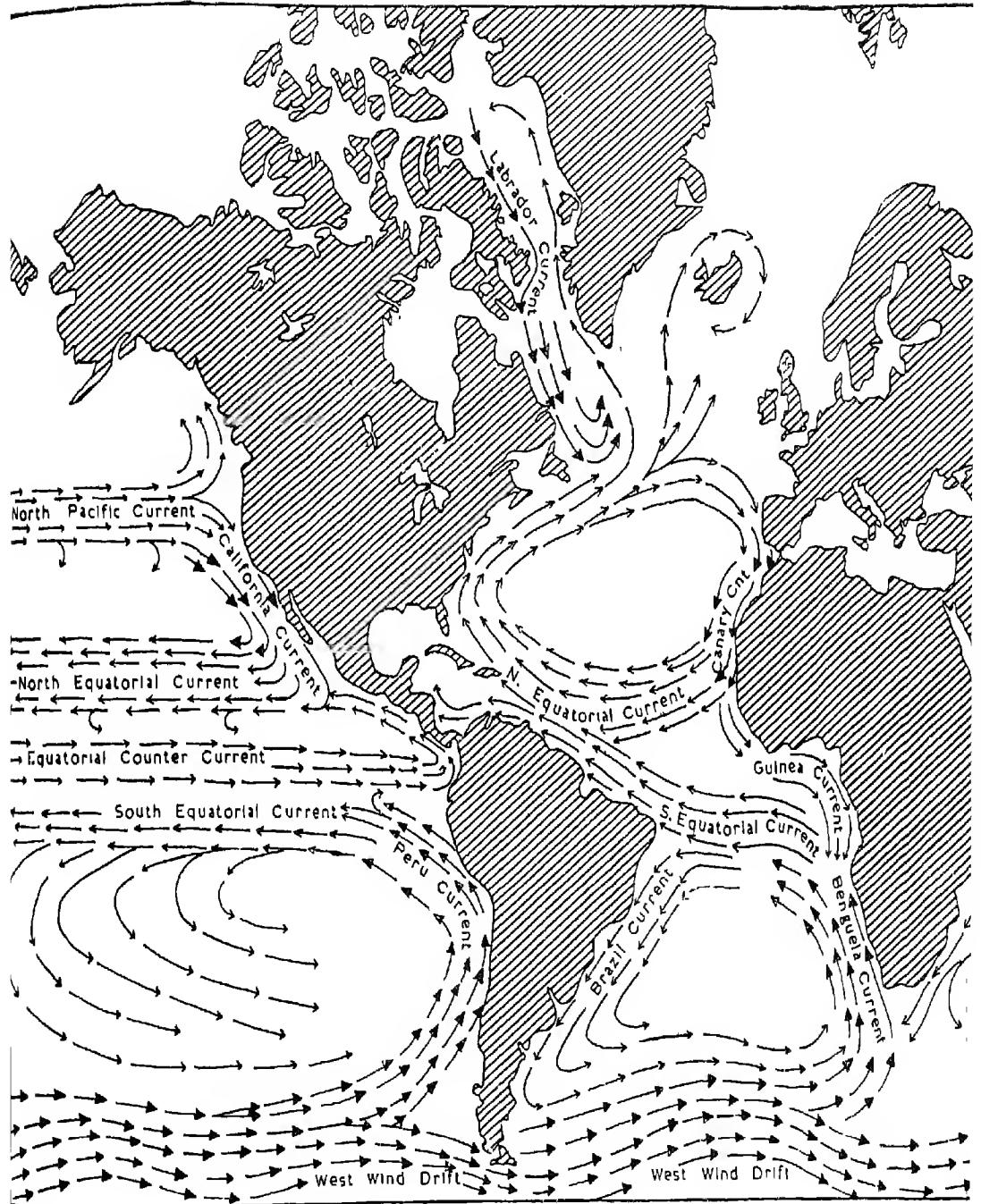


Fig. 108. Ocean Currents



comprises those of the Atlantic, the Pacific, and the Indian Ocean (Fig. 108)

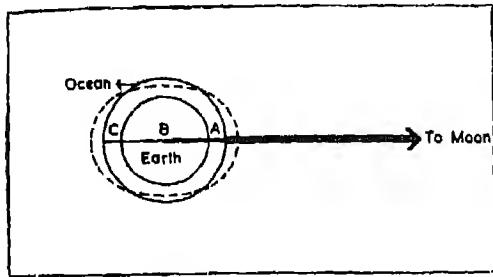


Fig. 109. Formation of Tide

In the Atlantic Ocean, the more important of the warm currents are the Gulf Stream, the North Equatorial Current, the South Equatorial Current, and the Brazil Current. The cold currents include the Labrador Current, the Canary Current, and the Benguela Current. Both in the North and South Atlantic Oceans, there are giant circulations of warm currents between the latitudes of  $10^{\circ}$  and  $40^{\circ}$ .

In the Pacific Ocean, the important warm currents are the Kuroshio, the North Pacific, the North Equatorial, the South Equatorial, and the Equatorial Counter Current. The cold currents include the Peru, California, and Alaska currents. There is a giant circular movement of the warm current in the North Pacific Ocean.

In the Indian Ocean, the South Equatorial and the South-west Monsoon are the noteworthy warm currents. The West Wind Drift, which is a cold current, flows west to east in the higher latitudes of  $40^{\circ}\text{S}$  and beyond toward the south pole. There are regional currents, such as the Agulhas, the Mozambique, and the West Australian. The Indian Counter current flows immediately south of the equator, while the warm Equatorial

Current between  $10^{\circ}$  and  $20^{\circ}\text{S}$ . There is a reversal of the current of the Indian Ocean due to the influence of the monsoons. In winter, the circulation of water, in the northern part of the Indian Ocean is counter-clockwise, while in the summer it is clockwise.

The currents not only flow at the surface of the sea water, but also underneath it. Such currents are caused by the differences in salinity and temperature. For example, heavy surface water of the Mediterranean Sea sinks and flows westward past Gibraltar as a sub-surface current.

#### Tides

Tides are the rhythmic rise and fall of the water in the oceans. The sea level forms a smooth curve with alternating maxima and minima, and the character of the surface is wavelike. Tides are produced by the attraction of the moon and the sun on the earth. Because the positions of these two heavenly bodies change with reference to the earth, the tides generated are of a complicated character and of different types.

The earth has uniform depth of ocean water covering it. The part at A being nearest to the moon is the most strongly attracted by it. At B, the attraction of the moon is weaker and at C, it is the weakest. The attraction of the moon decreases from A to C. The earth develops a tendency to be pulled apart. The ocean water at A pulls away from the earth and the earth pulls away from the ocean at C. Since water is fluid and free to flow, it moves toward the centres at A and C. These bulges of water are called the tides (Fig. 109).

The moon whose attraction produces

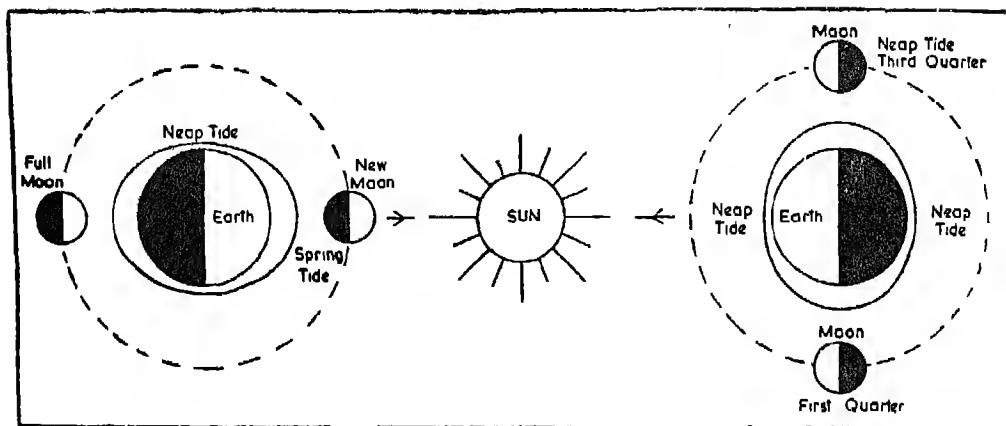


Fig. 110. Formation of Spring and Neap Tides

the tides revolves around the earth. But the earth with the moon revolves around the sun. Thus, in the formation of the tides three forces operate jointly or in opposition : the attractive force of the earth, the attractive force of the moon, and the attractive force of the sun.

There are two tides of a special occurrence: the spring tide and the neap tide (Fig 110). The spring tides are of an unusually great range. They occur about twice every

month, at new moon and full moon. At new moon, the sun and the moon are in conjunction and the joint attraction of the two bodies is very great. At full moon, the sun and the moon are in opposition and again the rise of water is great. In the first and the third quarter, the attraction of the sun and the moon tends to balance each other. The tides produced are of an unusually small range and are termed neap tides.

### EXERCISES

1. Discuss the factors which control the vertical and horizontal distribution of temperature in the oceans.
2. How do the ocean currents influence the distribution of temperature in the oceans ?
3. What is meant by the isoanomalous temperature of the sea water ?
4. How is salt formed in the oceans ?
5. Describe the distribution of salinity in the oceans.
6. Name the main types of waves and explain the modes of their origin.
7. Discuss the salient features of the ocean currents of the Atlantic Ocean.
8. How are tides formed ? Describe the formation of spring tides.

## OCEAN WATERS AND THEIR CIRCULATION

201

### Books for further study

Sverdrup, H.V., *Oceanography for Meteorologists*, New York : Prentice Hall, 1942.

Sverdrup, H.V., *The Oceans*, New York : Prentice-Hall, 1942.

King, C.A.M., *Oceanography*, London : Edwin Arnold, 1975.



## Marine Flora, Fauna and Deposits

The marine environment has a large variety of flora and fauna of all sizes. The marine environment itself is variable in properties. It has two main divisions : pelagic and benthic (Fig. 111). The former includes the entire mass of water, while the latter includes all of the ocean floor. The pelagic division is subdivided into neritic and oceanic provinces, horizontally. The two provinces are separated by a depth of 200 metres which corresponds to the edge of the continental shelf. The neritic waters have a depth of less than 200 metres, low salinity, less turbulent motion, more of plant nutrients, and large quantity of diatoms. This is the region of greatest importance to marine life in general. It is the natural habitat of the fish.

The oceanic province has a depth of

more than 200 metres. It has an upper lighted zone and a lower dark zone with their boundary at a depth of 200 metres. Broad, spatial expanses and great ranges of depth are the main characteristics of the oceanic province. The water is transparent and has no sediment of terrestrial origin. Its salinity is low and in its upper layer, plant nutrients occur in small quantity.

The benthic division comprises two systems : littoral and deep-sea. The two systems are separated by a depth of 200 metres. The littoral is characterised by the high and low tide levels. Here live isopods, gastropods, crustaceans and fishes. There is plentiful primary food for animals. The benthic zones have uniformly low temperatures,  $5^{\circ}$  to  $-1^{\circ}\text{C}$ , and have persistent darkness. Carnivorous animals are quite common. Sedimentary

deposits here are—terrigenous deposits, organic or pelagic oozes, and red clay. The amount of pelagic food for animals decreases with the increasing distance from the coast. Red clay at great depths is the poorest.

### Marine Vegetation

The marine vegetation is characterised by a limited variety. Algae, thallophyta, and the higher plants are quite common.

Algae are primitive plants in which the body shows little or no differentiation of vegetative organs. There is no true root, stem, or leaf. The algae are beautifully coloured. Blue-green, green, brown, red, and yellow-green algae have been identified. The first four are attached plants and the fifth is a floating variety. The smaller algae are epiphytic, growing on other

plants, and epizoic, growing on animals. The larger algae occur on rocky reefs in bands, some distance from the shore.

The blue-green algae are small plants, some of which have only one cell and some have many cells. This type occurs in fresh and brackish waters as well as in warm waters.

The green algae derive their pigmentation from chlorophyll. It occurs mainly in the upper littoral zone, especially in the lower half of the tidal zone. Its habitat is well-lighted. The fresh water algae are most closely related to green algae. The green algae are most abundantly found in the warm seas.

The brown algae occur almost wholly in the sea. Brown seaweeds are included in this type. Striking offshore growths of

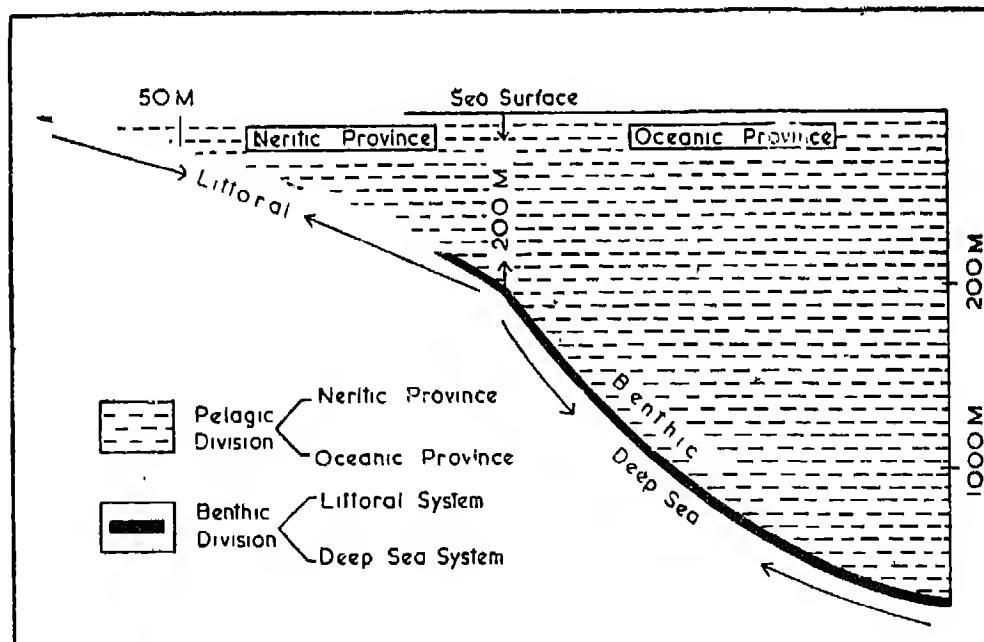


Fig. 111. The Principal Division of Marine Environment.

this type of algae are termed *kelp beds* which include giant seaweeds. These form marine forests on which feed myriads of neritic fish. Kelp beds are also harvested for commercial products. The brown algae display a great range of size and structure and are the most advanced of all thallophytes. The brown algae are ideally suited to cooler waters and occur in rocky coasts of higher latitudes. Some varieties, such as sargassum, occur in the tropical and sub-tropical regions.

Almost all of the red algae are marine. They are very beautiful and iridescent. The red algae are small in size, have a large variety of form, and are numerous. All are multicellular. These algae are distributed very widely but are most abundant in the temperate seas. They need subdued light. Their most luxuriant growth takes place in the subtidal zone. They form crusts on rocks in the littoral zone.

Yellow-green algae are both plants and plant-like animals and are mainly floating forms. They include diatoms, dinoflagellata, phaeocystis, halosphaera, and silicoflagellates. Of these, the most widely occurring are the diatoms.

The diatoms are microscopic in size and have a unicellular structure. All the diatoms are covered by shells. The shells are siliceous sediments and have formed enormous fossil deposits of the diatomaceous earth. In the economy of the sea, the diatom plants are the most important. The diatoms grow in the littoral zone as benthic forms or are attached to plants and animals.

The angiosperms or the flowering plants comprise the higher plants of the sea.

They do not originate locally in the sea but are brought in by the fresh-water movements. The angiosperms are important in parts of the sea where they provide detrital good for the marine animals.

The most striking characteristic of the sea animals is their endemism, i.e., they are specific to particular areas. Many species of the marine animals live together in the same area. The ecological range of most of the marine animals is rather limited.

#### Faunal Divisions

There are two broad faunal divisions: the *epipelagic* fauna of the continental shelf and the *bathypelagic* fauna of the deep ocean. The divisions are separated by the outer edge of the continental shelf. The epipelagic fauna are greatly influenced by temperature. There are fewer species in the higher latitudes than in the lower latitudes. Coral reef and mangrove swamp communities are two important ecological groups in the neritic tropical waters. Very rich fauna are characteristic of coral reefs.

There are three primary ecological groups of the marine animals: *benthos*, *nekton*, and *zooplankton*. The benthos are the animals of the sea floor. The nekton constitute the swimming animals, and the zooplankton refer to the floating animals.

The benthos group is subdivided into two types - the animals of the littoral zone and the animals of the deep sea. In the littoral zone, the supply of food for animals is very large. Hence, there is a great variety as well. Limpets, chitons, mussels, barnacles, corals, tube worms, hydroids, sponges, and anemones are the members of the sessile or immobile group. Free-moving members include sea urchins,

molluscs, corals, crabs, fish, and muddy bivalves. The littoral fauna reveals a horizontal grouping as well : arctic, antarctic and tropical. Those living on the sea-bottom are termed *demersal*.

The deep-sea benthos comprise two groups on the basis of depth : upper *archibenthic fauna* (continental deep-sea fauna) and *lower-abyssal fauna*, the dividing line being a depth of about 1000 metres. The animal life in the deeper sea is endemic because these animals can endure depth and cannot live in shallow waters. The number of species is small. The mud-isopods, shrimps, sponges, hydroids, tunicate and crinoids are common.

The nekton or the swimming animals are those which can swim against currents and waves with the help of their organs. They have sharp shape and are covered with slime. Adult fishes, squids, whales, dolphins, seals and crustaceans form this group. They occur all over the pelagic region and are both neritic and oceanic. The animals are migratory and roam through vast distances searching for their food. Salmon is a typical example of such migratory animal. Whale is a marine mammal which travels over long distances. Squids are the only invertebrate in this group. Pelagic prawn, otters and snakes also belong to the group. The nekton are of great significance to man because of their following characteristics : (i) large size of individual members, (ii) tendency to form schools, (iii) commercial value as food, and (iv) commercial value as oil. All the swimming animals, fish, are termed *pelagic*.

Zooplanktons, the floating animals, depend for their food on *phytoplankton*.

These include tintinnids; radiolarians, foraminifera, copepods, ostracods, euphausiids, amphipods, jellyfish, siphonophores, molluscs, and the pteropods. Different kinds of floating animals require different conditions of temperature and salinity. These animals have the habit of vertical migration, sinking down in the day and climbing up in the night. The floating animals have a patchy distribution. Some fish and other marine creatures feed directly on the zooplankton. In Japan, zooplankton is used to feed rainbow trout and as a fertilizer and in Norway as bait and food for trout and salmon. Zooplankton also includes many larval forms, such as eggs and larval stages of benthic and nektonic animals.

#### Marine Deposits

Marine deposits comprise the sediments which have been produced by the continuous wearing of rocks, and include the remains of plants and animals of the ocean floor. The study of the marine sediments is very important for the understanding of most of the rocks exposed at the surface of the earth. These rocks were once laid down under the sea. More knowledge of the history of the earth is also gained from the study of the marine sediments.

On the basis of their origin, the sediments can be classified under six groups : (i) detrital material, of immediate terrigenous origin, (ii) products of subaerial and submarine volcanism, (iii) skeletal remains of organisms and organic matter, (iv) inorganic precipitates from the sea water, (v) products of chemical transformations taking place in the sea, and (vi) extraterrestrial materials.

The first comprises broken material derived from the sedimentary and igneous

rocks of the immediate land. Breaking through mechanical processes and decomposition through chemical processes results in the formation of these sediments.

Subaerial and submarine volcanoes throw out lava. The lava of subaerial volcanoes is mechanically and chemically weathered and then transported to the sea by air and running water. The volcanic material is deposited over a large area. Lava fragments, volcanic glass, pumice and mineral grains form the unchanged volcanic material. Submarine volcanism leads to the formation of the volcanic oceanic islands.

The marine organisms have hard skeletal structures. These mainly comprise calcareous and siliceous materials. The skeletal structures are changed into sediments by mechanical and chemical processes. The benthic animals constitute a large proportion of the calcareous sediments. Plant remains also contribute a large share to these sediments.

Inorganic precipitates are formed by the solution of some substance when the amount of the substance is very large and cannot be dissolved any further. Precipitation also results from evaporation in lagoons and closed seas. Calcium carbonate, dolomite, iron and manganese oxides, phosphate, barite, pyrite, and ferrous sulphide form the main inorganic precipitates.

Products of chemical changes taking place in the sea are those substances formed by the interaction of the sea water and solid particles. Glauconite, phosphosite, feldspar, philliosite and clay minerals are some of the examples.

Extra-terrestrial materials are small black and brown crystalline particles found in the red clay. The particles are either of

iron or iron alloy but are very rare. Most of these substances have been derived directly or indirectly from many meteorites.

The marine deposits can be subdivided into two main groups : *pelagic* and *terrigenous*. The pelagic deposits are found in deeper water, far from the shore and may be either organic or inorganic in origin. The terrigenous deposits are found near the shore and contain some coarse material derived from the adjacent land.

The pelagic deposits are classified into two groups : inorganic and organic. The inorganic group is represented by the red clay. The organic deposits comprise calcareous and siliceous oozes. Calcareous oozes contain globigerina, pteropod, and coccolith members. Siliceous oozes are constituted by diatom and radiolaria oozes.

The terrigenous deposits include sand, silty sand, sandy silt, silty mud, and clayey mud. Both organic and inorganic terrigenous deposits have been identified. The foraminiferal, coral, and diatomaceous deposits represent the former. The glacial, volcanic, and micaceous represent the latter.

The red clay is the predominant type of the pelagic deposit. It covers a total area of 102 million sq. km., which is about 38 percent of the oceanic area. About half of this area is concentrated in the Pacific Ocean. The red clay occurs at average depths of about 5000 metres.

In the chemical composition of the red clay, the two most important components are silicon and aluminium dioxides having proportions of 54 percent and 16 percent, respectively. The red clay also contains iron, manganese, phosphorus, and radium.

Oozes contain more than 30 percent of

material of organic origin. Calcareous oozes contain more than 30 percent calcium carbonate. Globigerina ooze is related to pelagic foraminifera and pteropod ooze contains shells of pelagic molluscs. Coccolith ooze contains a large number of coccoliths and rhabdoliths.

Siliceous oozes contain a large proportion of siliceous skeletal material produced by planktonic plants and animals. Diatom oozes are produced by plankton plants. Radiolarian oozes are produced by planktonic animals.

According to their location, the marine deposits can be classified into three groups : continental or terrigenous, neritic and pelagic. The first includes the littoral, shallow-water, and terrigenous mud deposits. About 70 per cent of the deposits consist of quartz. Littoral deposits consist primarily of boulders, gravel, sand, and mud. Mollusca, crustacea, and echinoids are found mixed in this material. Shallow-water deposits consist of boulders, gravel, sand and occur from the shore up to depths of 600 metres. The material is mostly derived from land, volcanic eruptions and organic calcareous detritus. Terrigenous mud occurs beyond a depth of 600 metres and include blue, red, and green mud.

The neritic deposits contain organic shells and skeletons of various animals and plants occur up to depth of 300 metres. Deep-water neritic deposits occur around the oceanic islands. Here, coral formation is specially important.

The pelagic deposits cover about 75 percent of the oceanic area. Benthos, nekton and plankton produce the pelagic deposits. The red clay is an inorganic pelagic deposit.

### Corals

Coral reefs are masses of limestone and dolomite. These are accumulated by coral polyps. The corals are cemented by solution and calcareous sand. The reefs are essentially the remains of calcareous organisms and algae.

Coral polyps need, for their growth, a temperature of about 20°C. They live within depths of about 80 metres where sunlight is abundant. The corals need sediment-free, clear water. Both fresh water and highly saline water are harmful to the growth of the corals. Coral reefs grow on a submarine bench or a platform. The benches and platforms should have depths of within 300 metres located along the continental shores and islands in open seas. Living corals occur in depressions or toward the outer margin of the reef into the open seas. Most coral reefs were formed on the sea bottom when it was at a higher level or the sea surface was lower than at present.

Three types of reefs have been recognised : (i) fringing, (ii) barrier, and (iii) atoll, on the basis of their characteristics and mode of occurrence (Fig. 112).

The fringing reef is a belt of reef that grows around islands or along the coasts. It grows from the deep sea bottom. Its growth is checked along the mouths of large rivers. The fringing reef is a narrow belt. Its seaward edge is higher than the landward portions. The surface of the reef is rough and is located above the level of low water. The waves deposit coral fragments and form a boulder zone which is called *reef flat*. The reef is closely attached to the coast and the island. One can, therefore, climb up the slopes of the

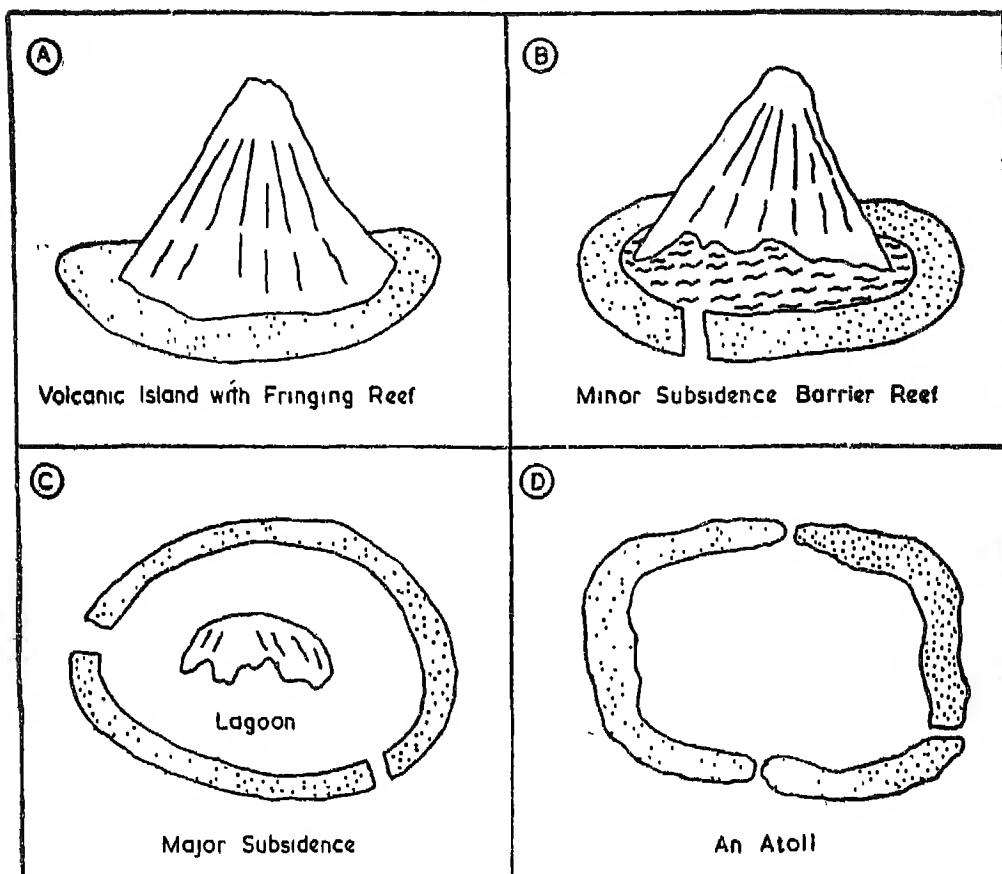


Fig. 112. Types of Reefs

island directly from the fringing reef. The living corals do not extend outward because of the sudden and large increase of the depth. The fringing reefs occur in the New Hebrides, Society Islands, and off the southern Florida Coast. Near Rameshwaram in south India is to be found a fringing reef.

The barrier reef is the largest of the three types. It develops on a coastal platform. It is formed by the accumulation of corals of various sizes. Boulders, coral debris and sand deposits occur on

the surface. The essential characteristic of this reef is its distant location from the coast or the island. There is a shallow and broad lagoon that separates the barrier reef from the island. The island experiences minor subsidence, while the coral reef has built itself up. The barrier reef is very thick. Its base extends below a depth of about 180 metres. It has very steep seaward slopes and a width of several kilometres. Small channels cut across the barrier connect the lagoon with the open sea. Along the coasts, its

length runs hundreds of kilometres. The most extensive of all the barrier reefs is the Great Barrier Reef of Australia, covering a distance of 1900 km along the coast of Queensland. The lagoon is about 70 m deep and 15 to 120 km in width.

Atoll is a circular coral reef surrounding a lagoon either having an island or a submerged plateau in it. A large number of channels cutting across the atoll reef join the lagoon with the open sea. Atoll is located at great distances from the deep sea platforms. Atoll is covered with palm and coconut trees. The lagoon has a depth of 80 to 150 metres. There are three types of atolls : (i) a true atoll, which has a circular shape and encloses a shallow lagoon with no island in it ; (ii) an atoll which surrounds a lagoon with an island in it ; and (iii) a coral island or atoll island in which island crowns are formed on the reef by erosion and deposition. Atolls are far more common in the Pacific than in any other ocean. These atolls occur in groups. The Fiji Atoll and the Funafuti Atoll in the Ellice Island are well-known examples of atolls. A large number of atolls occur in the Laksha Dweep Islands.

The origin of the coral reef has been explained by two theories : (i) subsidence theory, and (ii) standstill theory.

According to the subsidence theory, the island around which the fringing reef develops subsides slowly. Corals continue to build upward and outward. A body of water invades between the sinking island

and the growing reef. This body of water is retained in its place by the higher outer edge and the lower inner edge of the reef. This body of water is the lagoon and the surrounding reef is the barrier reef. Ultimately, the island sinks completely and disappears below the water level. There is now a continuous sheet of circular or oval-shaped water body termed lagoon and the surrounding reef is then termed as atoll. The most important idea is that the rate of the sinking of the island is slower than the rate at which the corals are built upward and outward.

According to the standstill theory, the wave-cut platform, on which the corals build a reef and ultimately an atoll reef, remains stable. In the case of some atolls, there is no change in the sea level while the corals continue to build up the reef on the stable platform. The reef is built up gradually and then finally appears above the water level. The reef is built outward, it also extends deeper into the sea. Many of these atolls are built around volcanic summits as well. The summit is changed into a depression by solution action and is then filled with water to form a lagoon.

In the case of some other atolls, reef building took place on the platform first and then there was a lowering of the water level. The lowering has exposed the atoll reef above the water level. This happened during the Pleistocene Ice Age when the sea water became locked in the land in the form of glaciers,

## EXERCISES

1. Name the plant and animal zones of the oceans and mention their characteristics.
2. Classify the marine deposits in terms of their origin.
3. Describe the various types of oozes.
4. What is meant by the pelagic deposits ?
5. Discuss how coral reefs are formed

## Books for further study

King, C.A.M., *Oceanography*, London : Arnold, 1975.

King, C.A.M., *Beaches and Coasts*, London : Edwin Arnold, 1959.

Steers, J.A. *The Sea Coast*, London :

Guilcher, A., *Coastal and Submarine Morphology*, New York : J. Wiley, 1958.



## CHAPTER 24

# Marine Resources

**I**t is not generally appreciated that the oceans constitute a vast storehouse of resources of a large variety, and, in particular, of the living resources. The chemical, biological, and geological resources of the oceans have literally incalculable value. Within the ocean, the continental shelf is a source of a major part of geological and biological resources.

### Sources of Minerals

There are a large number of minerals which could be mined from the sea. The main oceanic minerals are phosphorite, manganese, sand, gravel, titanium, zircon, tin, diamonds, monazite, iron, gold, oil, gas, and sulphur. Oil, gas, sand, and gravel form the major part of the oceanic

geological resources. The most important potential resource is phosphorite. Manganese nodules also occur widely, particularly in the Pacific Ocean. These nodules accumulate on the sea-floor at the rate of six million tons per year. Iodine, salt, bromine, soda, and magnesium are also abundantly mined from the oceans. A single cubic mile of the oceanic water contains approximately 6,000,000 tons of magnesium.

### Natural Oil and Gas

The most important mineral produced from the sea is oil and gas. It accounts for more than 90 percent of the value of minerals obtained from the oceans. The off shore oil and gas production amount to 17 percent and 6 percent respectively,

of the total in the non-communist countries of the world. It is estimated that, by 1980, about 35 percent of all the world's oil production will come from the oceans. The Bombay High is now an important oil producer of India. Most of the oil and gas now comes from the continental shelf but in future the continental rises will also be tapped increasingly.

#### *Fish*

Ocean is a source of fish, crustaceans, mollusks, and other edible forms of animal life. Together with the seaweeds, they constitute the biotic marine resources. Not all sea animals are used as food. Seal is used to provide only furs. Whales, sea cows, sea lions, manatees, and other sea mammals provide meat, oil, leather and other products.

Fish, of an enormously large variety, constitutes the major biotic resource of the oceans and has been caught and consumed since the prehistoric times by man throughout the world. The fundamental basis of fish resources, as of all the marine biotic resources, is the phytoplankton which are minute plants drifting at the mercy of the surface currents. Modern fishing methods are still of hunting type, but different methods are used according to the differing behaviour of fish. The total catch of fish is spread very unevenly over the oceans, with the Pacific, the Atlantic and the Indian ocean providing 30, 23 and 3 million tons, respectively, in 1969. Herring, anchovy, cod, hake, haddock, mackerel, red fish, basses, congers, and tuna are some of the widespread catches. Of these, the herring type accounts for

the largest share. In 1969, its total catch was about 18 million tons. Both the demersal fish which live near the bottom of the sea and the pelagic which swim and live near the surface are caught throughout the world.

The chief fisheries of the world are concentrated in the shallower waters of the continental shelves and over the banks in the Northern Hemisphere. These areas provide the best supply of phytoplanktons, the food for fish. Four major commercial fishing regions of the world have been identified : (i) the seas of north-western Europe, (ii) the Great Banks and adjacent waters, (iii) the seas of North-eastern Asia, and (iv) the waters off north-western North America. The most spectacular rise, however, has been that of the Peruvian area which has been at the top of the world's fishing nations for several years now.

Seaweed is being used for an increasing number of purposes, as human food, animal feed, in textile manufacture and in cooking. It is a sublittoral resource. Japan, Norway, Canada and Scotland are the main producers. Japan's production in 1965 was about 395,000 metric tons.

#### *Energy*

The energy resource of the oceans comes from the tidal fluctuations. These are highly irregular and, therefore, the devices for generating power from the tides will have to be very costly. Only those pockets of the seas where the tides are extremely high and low and where they can be dammed in long, narrow bays provides the sites for generating power from the tides. The tidal power station on the Rance in North France is very

successful, and produces 800 million oil exploration and production, deep-sea kilowatt hours of energy per year, mining of strategic minerals, and produc-

The future uses of the oceans will include desalinated fresh water, deep-sea

